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NATURAL HISTORY

BRITISH MUSEUM (NATURAL HISTORY)

BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910

NATURAL HISTORY REPORTS

GEOLOGY. VOLS. I and II

LONDON:
TRUSTEES OF THE BRITISH MUSEUM (NATURAL HISTORY).

1964

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NATURAL HISTORY

VOLS. I and II.

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BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910.
NATURAL HISTORY REPORT.

GEOLOGY. VOL. I.—No. 1, pp. 1–49.

ANTARCTIC FOSSIL PLANTS.

BY

A. C. SEWARD, F.R.S.,
Hon. Sc.D. Dublin, Professor of Botany in the University of Cambridge.

PLATES I–VIII; MAPS A–C; TEXT-FIGURES 1–6.

LONDON:
PRINTED BY ORDER OF THE TRUSTEES OF THE BRITISH MUSEUM.
Sold by Longmans, Green & Co., 39, Paternoster Row, London, E.C.; B. Quaritch, 11, Grafton Street, New Bond Street,
London, W.; Dulau & Co., Ltd., 37 Soho Square, London, W.; and the Midland Educational Co., Ltd.,
41 and 43, Corporation Street, Birmingham;
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British Museum (Natural History), Cromwell Road, London, S.W.
1914

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[*Issued 24th October*, 1914.]

BRITISH MUSEUM (NATURAL HISTORY).

BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910.

NATURAL HISTORY REPORT.

THE Trustees of the British Museum have undertaken the publication of the Natural History results of the British Antarctic ("Terra Nova") Expedition, 1910, sent out under the command of the late Capt. R. F. Scott, R.N., C.V.O., and arrangements have been made for working out most of the groups of specimens collected.

It may be useful to explain that it is proposed to issue the memoirs from time to time, as they become ready for publication. By adopting this method the delay that results from waiting until a volume is completed will be avoided. When a volume has reached a convenient size it will be completed by the issue of a title-page and table of contents.

Professor Seward's account of the Antarctic Fossil Plants is the first of the Geological Memoirs to be completed.

L. FLETCHER,
Director.

BRITISH MUSEUM (NATURAL HISTORY),
LONDON, S.W.
Oct. 24, 1914.

ANTARCTIC FOSSIL PLANTS.

By A. C. SEWARD, F.R.S., Hon. Sc.D. Dublin, Professor of Botany in the University of Cambridge.

INTRODUCTORY NOTE.

The description of specimens embodied in the following pages was undertaken at the invitation of the Trustees of the British Museum, and the material was handed to me on May 15 of this year by Mr. Raymond Priestley and Mr. Debenham.

I desire to thank Mrs. Wilson for her kindness in allowing me to make use of passages from Dr. Wilson's diary, and for permission to reproduce two of the pencil-sketches of Buckley Island. I have availed myself freely of generous offers of assistance from Mr. Priestley, Mr. Debenham, and Mr. Lillie. Lieut. Rennick, another member of the Expedition, called my attention to the map of the Antarctic Regions published by Messrs. Stanford, a simplified form of which is reproduced as Map C. Dr. Smith Woodward has in various ways lightened my pleasant task, which has been carried out in circumstances allowing but a narrow margin of time for its completion. Mr. W. N. Edwards, of the Geological Department of the British Museum, has also kindly assisted me in the correction of the proofs. I wish especially to record my appreciation of the trouble taken by Mr. T. A. Brock in the execution of the accurate drawings reproduced in Plate III. I am indebted to Mr. Tams for the excellent series of photo-micrographs of the indifferently preserved stem reproduced in Plates IV–VIII.

I. PALAEOBOTANICAL RECORDS FROM SOUTH VICTORIA LAND AND ADÉLIE LAND.

1.—CAPT. SCOTT'S FIRST EXPEDITION.

The records of fossil plants from South Victoria Land prior to 1912, though of considerable interest as demonstrating the former existence of plants on the Antarctic continent, are not in themselves of great botanical or geological value. Their discovery emphasised the desirability of further search and raised hopes for the future which have been fully realised. Mr. H. T. Ferrar, geologist to Capt. Scott's Antarctic

Expedition of 1901–04, was the first to discover traces of ancient plant-life in Antarctica. The specimens, collected at two localities—(i) the south-west arm of the Ferrar Glacier (Map A, north of 78° S. lat.), and (ii) the Inland Forts, four hills of sandstone capped by dolerite—were examined by Dr. Arber, who briefly described the unpromising material in a Report published in the Natural History volume of the Scientific Results of the Expedition.[1] The material obtained from a band 200 ft. below a dolerite sill intruded into the sedimentary strata, called by Ferrar[2] the Beacon Sandstone, shows "carbonaceous impressions of markings, which in all probability are of vegetable origin." My own examination of the specimens enables me to express agreement with this conclusion. The specimens from the Inland Forts are also indeterminable, and, as Dr. Arber says, "it is impossible to form any opinion as to the nature of the carbonaceous substance."

2.—SIR ERNEST SHACKLETON'S EXPEDITION.

A piece of fine-grained sandstone containing a black band $\frac{1}{4}$ inch thick was found by the Southern Party of Sir Ernest Shackleton's Expedition on December 11, 1908, "below the great nunatak in lat. 85° S.,"[3] in a moraine near the Cloudmaker mountain on the Beardmore Glacier (Map A). This black band was described by Mr. E. J. Goddard[4] as coniferous wood. The structure is, unfortunately, very imperfectly preserved, and an examination of the published photo-micrographs and others shown to me by Mr. Priestley confirms the conclusion that precise determination is impossible. In the absence of clearly preserved pitting on the walls of the elements composing the homogeneous wood, it is impossible to say whether the plant was a Conifer or a member of the Cordaitales, a group of Gymnosperms which reached its maximum development in the latter part of the Carboniferous period, or possibly the wood of some other extinct type of Gymnosperm. The specimen is interesting as the first undoubted record of an arborescent plant from the Beacon Sandstone series.

3.—SIR DOUGLAS MAWSON'S AUSTRALASIAN ANTARCTIC EXPEDITION (1911–1914).

Mr. Priestley informs me that carbonaceous markings were found by members of Sir Douglas Mawson's Expedition in carbonaceous shale, believed by Prof. Edgeworth David to belong to the Beacon Sandstone series, exposed on nunatakker in Adélie Land (Map C, 67° S. lat. 140° long.), 250 miles east of Headquarters.

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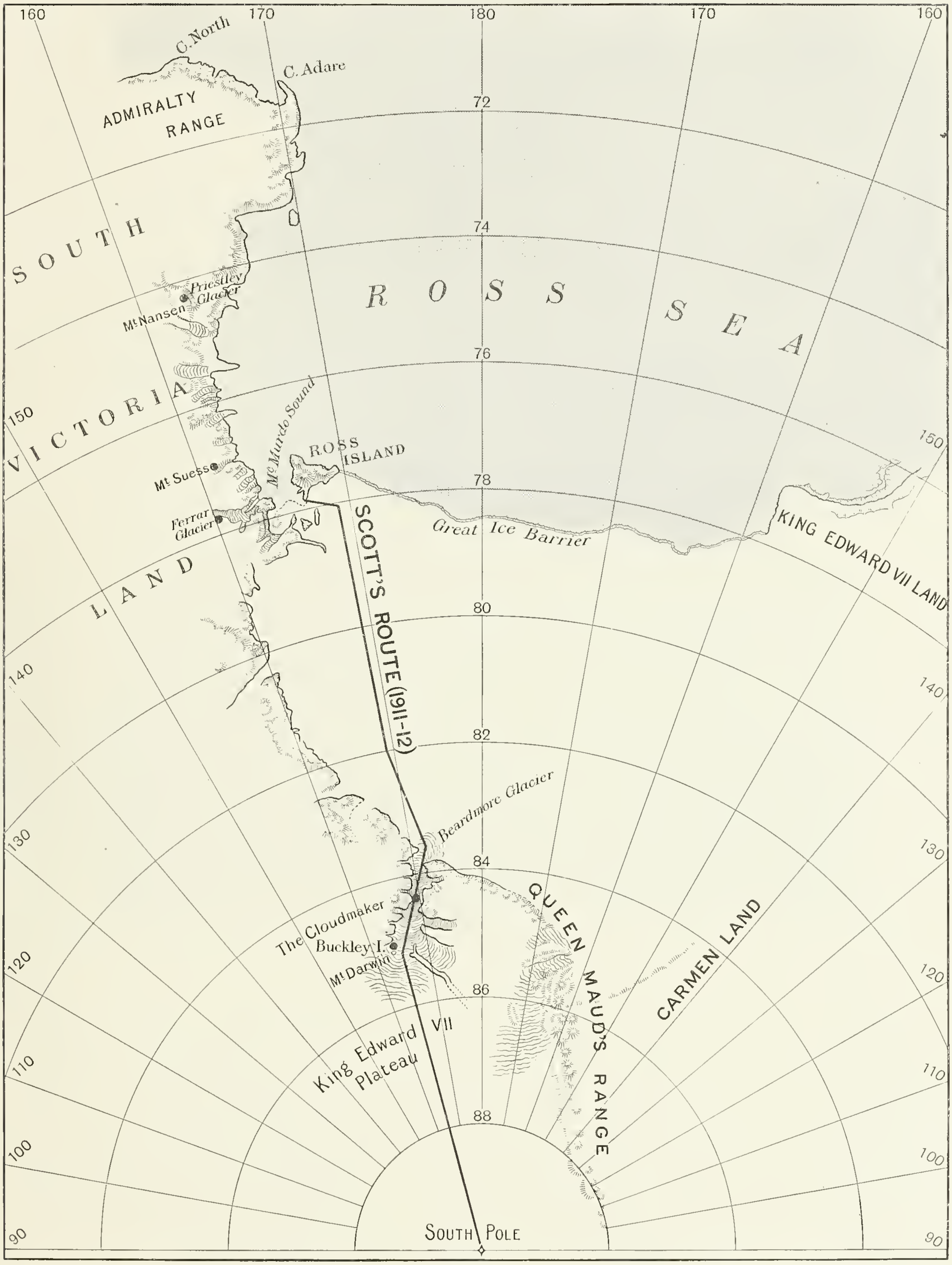
[1] National Antarctic Expedition, 1901–04. Natural History. Vol. I. Geology, p. 48. *London*, 1907.

[2] *Op. cit.* p. 39.

[3] The Heart of the Antarctic, being the Story of the British Antarctic Expedition, 1907–1909, by E. H. Shackleton. Vol. I, p. 320.

[4] *Op. cit.* vol. II, p. 300.



MAP A.—A portion of the Antarctic regions showing Capt. Scott's route to the South Pole and the localities, indicated by black dots, where fossil plants, or indications of plants, have been discovered. The map is based on the general map published in Sir Ernest Shackleton's book "The Heart of the Antarctic," with some additions from Capt. Amundsen's map published in "The South Pole" (1912).

4.—CAPT. SCOTT'S SECOND EXPEDITION.

In the course of the Western Geological Journey by members of Capt. Scott's last expedition Mr. Debenham found pieces of impure coal containing fragments of carbonised tissue in a moraine at the foot of Mt. Suess (Map A, 77° S. lat.). It was at this locality that the Upper Devonian fish-scales identified by Dr. Smith Woodward were discovered.

In his account of the Journey of the Northern Party, Commander (then Lieutenant) Campbell records the discovery on January 27, 1912, of a sandstone containing fossil wood (specimen E, Pl. II, figs. 6 and 7), and on February 1 he wrote: "During the day I found one large piece of sandstone with the impression of part of a fossil tree"[1] (specimen A). The photographs reproduced on Pl. II, figs. 6 and 7, show the imperfectly preserved tissue of the specimen found on January 27, and a piece of the fossil tree collected on February 1 is reproduced in text-fig. 1 and in Fig. 1, Pl. I. On February 2, he adds: "We spent the forenoon breaking up a big boulder [arkose conglomerate], a longer job than we expected, as the lower half was embedded in the frozen soil. After digging it out and rolling it over, Priestley split it open. Inside

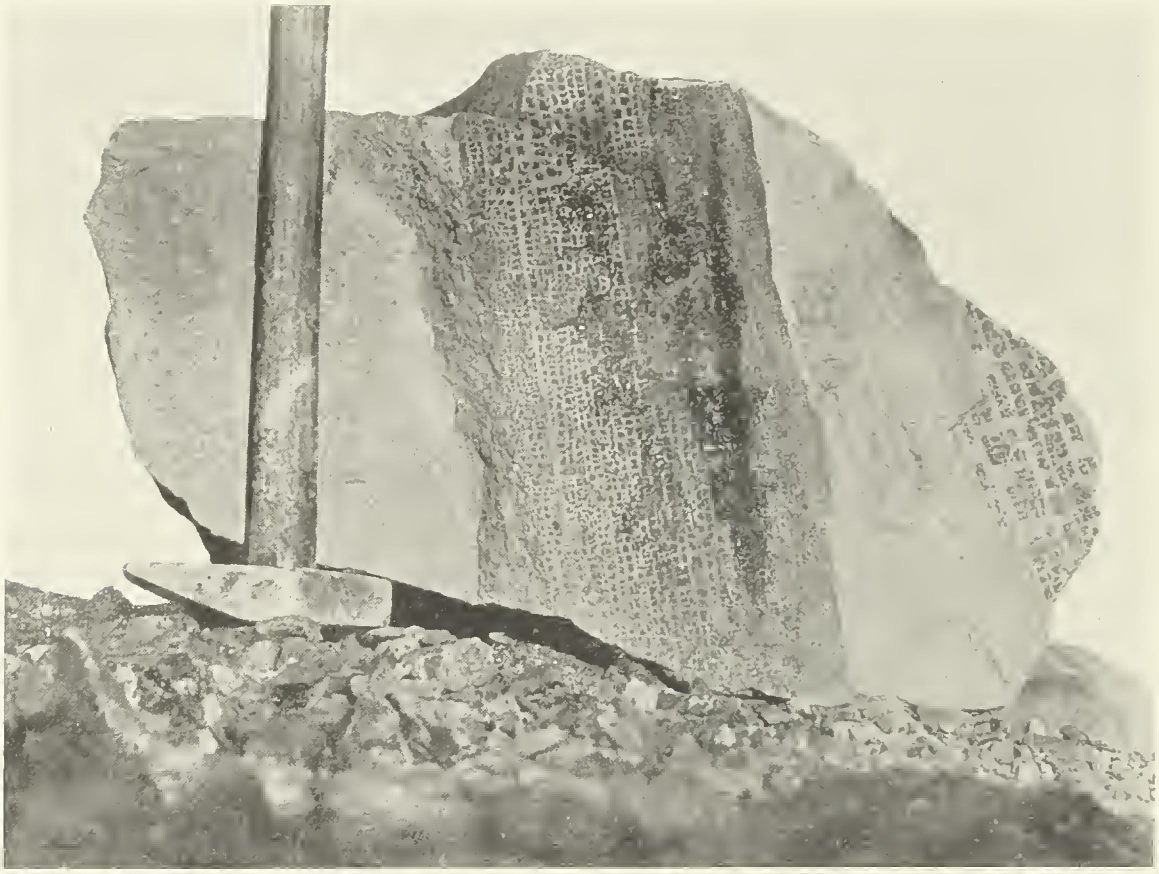


FIG. 1.—Specimen A. Charred wood in quartzitic sandstone from the moraine on the Priestley Glacier shown in text-fig. 2. From a photograph by Surgeon Levick, R.N. $\frac{1}{5}$ nat. size. (See also Pl. I., fig. 1.)

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[1] Scott's Last Expedition, Vol. II, p. 123. *London*, 1913.

was found a beautiful specimen of wood. Levick photographed it before we proceeded to break it up, as we knew we could never get it out whole." The wood (*Antarcticoxylon Priestleyi*), found on a moraine on the Priestley Glacier south of 74° S. lat. (Map A; text-fig. 2), is illustrated in text-fig. 3 and on Pls. IV–VIII. Mr. Priestley wrote in his diary on the same day (February 2): "Found one piece a foot long and 3 inches broad by an inch thick, but did not get the whole of it out."

The other fossil plants brought home by the "Terra Nova" are those discovered by the Polar Party in February, 1912. In his Journal of February 8, Capt. Scott wrote:[1]—"We lunched at 2 well down towards Mt. Buckley (Map A, 85° S. lat.; text-figs. 4 and 5), the wind half a gale and everybody very cold and cheerless. However, better things were to follow . . . the moraine was obviously so interesting that when we had advanced some miles and got out of the wind I decided to camp and spend the rest of the day geologising. . . . We found ourselves under perpendicular walls of Beacon sandstone, weathering rapidly and carrying veritable coal seams. From the last, Wilson, with his sharp eyes, has picked several pieces of coal with beautifully traced leaves in layers [*Glossopteris indica* Schimp.; Pl. II, fig. 8, etc.], also some

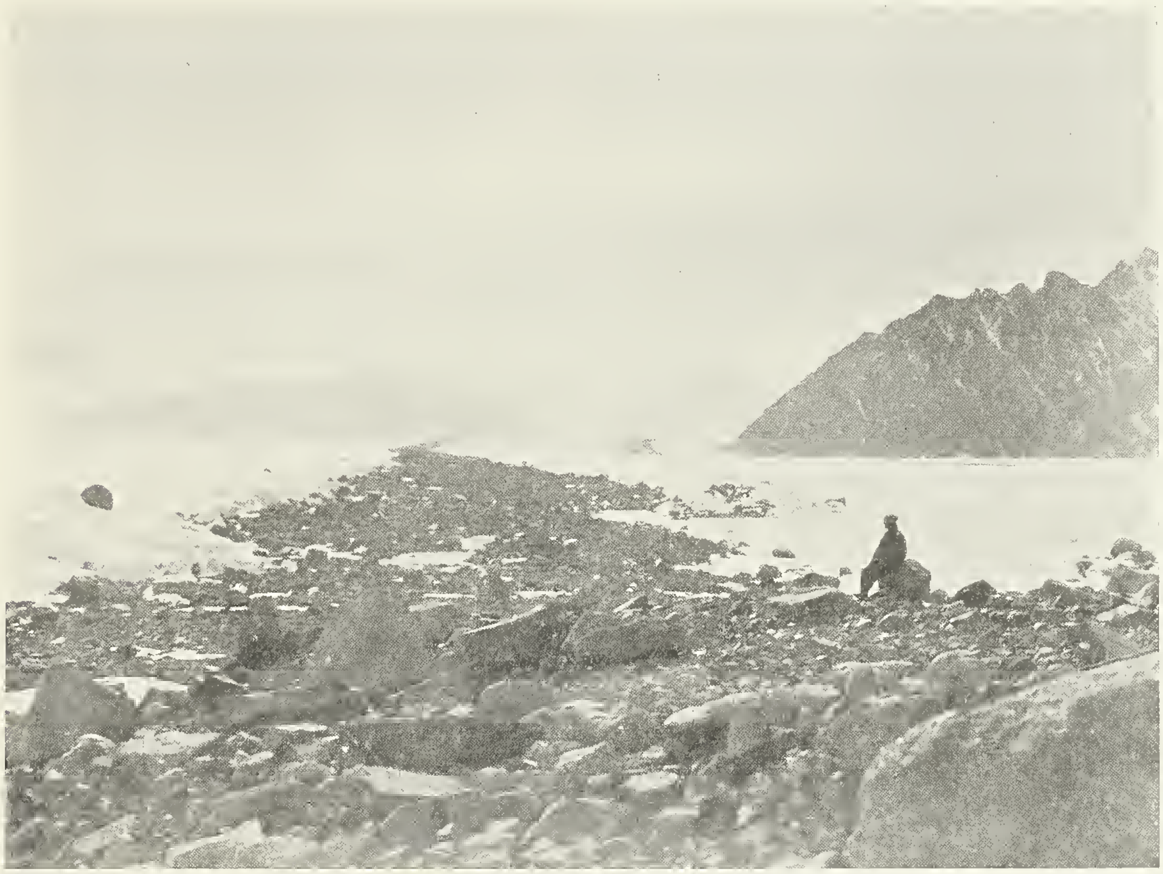

FIG. 2.—The medial moraine on the Priestley Glacier, on the west side of which the sandstone boulders were found containing the stem of *Antarcticoxylon* and other plant remains (specimens A and B). The photograph, taken by Surgeon Levick, R.N., looks N.N.W.; the boulders on the west side being derived from hills to the west, from which they were brought by a tributary glacier.

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[1] *Op. cit.* Vol. I, p. 564.

excellently preserved impressions of thick stems, showing cellular structure" (specimen C: Pl. I, fig. 3). On the following day after travelling 13 miles they "kept along the edge of the moraine to the end of Mt. Buckley. . . Wilson got pieces of vegetable impressions in pieces of limestone" [calcareous sandstone].

It was on the return from the Pole, only three days before Capt. Scott began his diary with the words: "In a very critical condition," and less than six weeks before the last entry was made, that the fossils were collected. In his account of the Geological History of South Victoria Land Mr. Debenham writes: "The 35lbs. of specimens brought back by the Polar Party from Mt. Buckley contain impressions of fossil plants of late Palaeozoic age, some of which a cursory inspection identifies as occurring in other parts of the world. When fully examined, they will assuredly prove to be of the highest geological importance."[1] The impressions referred to are leaves of *Glossopteris*, one of the few genera that can be identified with confidence from fragmentary specimens. Their occurrence 300 miles from the Pole is not merely a fact of the greatest interest, but, considering the fragmentary nature of the material, it is a cause of profound satisfaction that the best preserved specimens

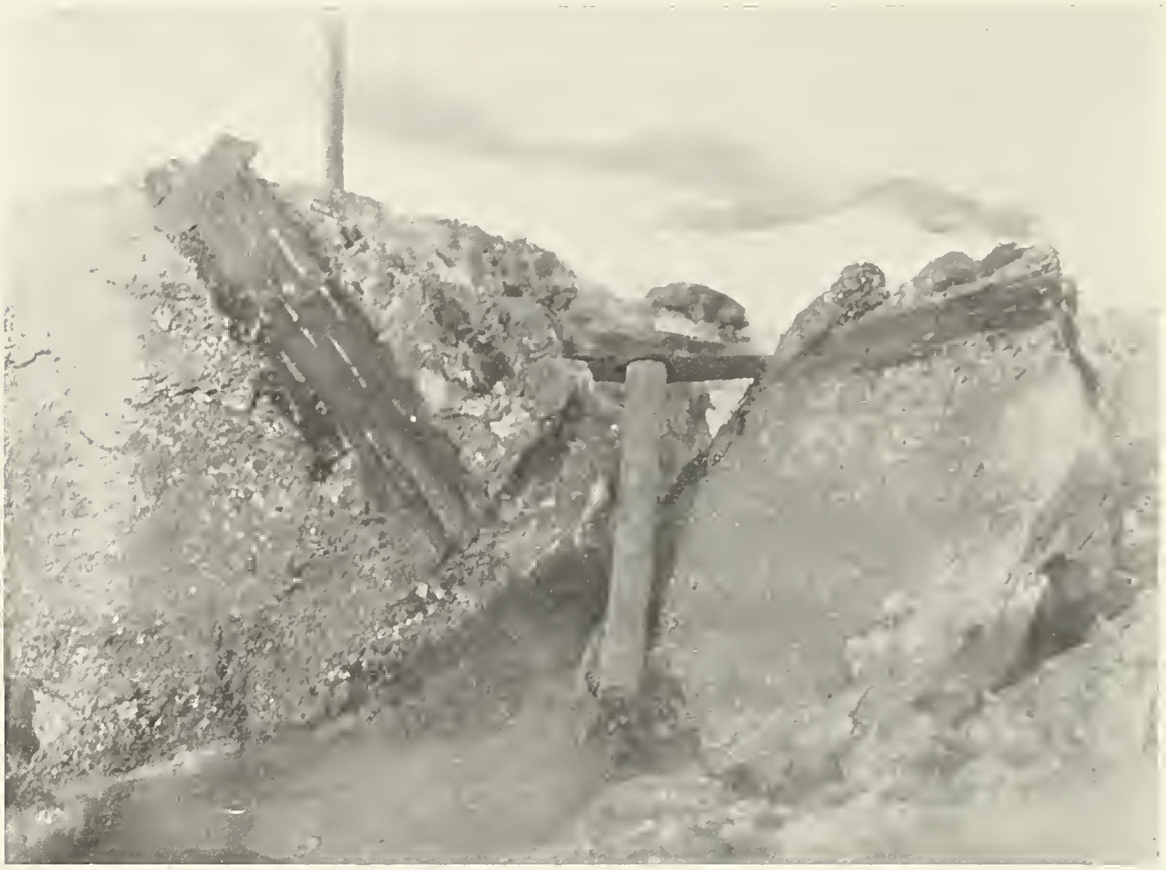

FIG. 3.—Broken sandstone boulder on the Priestley Glacier moraine containing the petrified stem of *Antarcticoxylon Priestleyi*. From a photograph by Surgeon Levick, R.N. $\frac{1}{5}$ nat. size. In the left-hand piece the spiral disposition of the elongated light patches, marking the position of leaf-traces, is clearly shown.

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[1] *Op. cit.* Vol. II, p. 437.

collected by Dr. Wilson and Lieut. Bowers leave no shadow of doubt as to their generic position. The discovery of *Glossopteris* was singularly fortunate; it is one of the most widely distributed and characteristic members of a flora which, from the point of view both of palaeo-phytogeography and of geological history in the widest sense, is of the greatest interest. As Mr. Debenham says in his summary of Geological Journeys: "The notes made by Dr. Wilson and the specimens collected by him and by Lieut. Bowers are perhaps the most important of all the geological results. The plant fossils collected by this party are the best preserved of any yet found in this quadrant of the Antarctic, and are of the character best suited to settle a long-standing controversy between geologists as to the nature of the former union between Antarctica and Australasia."[1]

Mount Buckley, or Buckley Island (text-figs. 4 and 5), is a nunatak rising to a height of 8,000 feet from the Beardmore Glacier in lat. 85° S. One of the last pencil sketches made by Dr. Wilson on the return journey from the Pole is that of Mt. Buckley reproduced in Scott's "Last Expedition."[2] In text-fig. 6, A and B, are reproduced two sketches of the same nunatak made by Dr. Wilson on the outward journey in December, 1912. The sandstone forming the greater part of the cliffs belongs to the Beacon Sandstone series; it is capped by dolerite, a part of the McMurdo sill which extends from 71° to 85° S. lat. and probably still further south. In the moraine at the foot of the cliff were found large boulders of calcareous sandstone called by Dr. Wilson limestone, and believed

Fig. 4.—Buckley Island from the Beardmore Glacier. From a photograph by Mr. C. S. Wright.

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[1] *Op. cit.* Vol. II, p. 438.

[2] Vol. I, p. 566.

by him to have come from some locality between Mt. Darwin (Map A, 85° S. lat.) and Mt. Buckley, "where a very heavy glacier comes down from the mountains at the back and from the summit." In the enormous sandstone boulders, derived from the Beacon Sandstone, were found some fossils described by Dr. Wilson in his diary as: "long stalks of vegetable origin . . . from $\frac{1}{2}$ to $\frac{3}{4}$ inch across, with cellular markings in cast with black crystalline coal fragments in pits" (specimen C). One of these stalks is reproduced in Pl. I, fig. 3. Coal seams were abundant in the Beacon Sandstone cliff: "none of them," writes Wilson, "were deep or broad, a few feet of dark blackish slaty, shaly, or coaly matter, some of it very soft, some exceedingly hard, some splitting easily, and some breaking vertically into blocks. . . In the cliffs the coal seams are arranged at irregular intervals, but making very regular bands." Dr. Wilson continues: "As we travelled along the cliffs on the 9th, we saw one or two seams of very genuine and really black coal. . . There were to be found in many of the sandstone blocks twisted bands of coal, much contorted and full of vegetable remains. . . But the best leaf-impressions and the most obvious were in the rotten lumps of weathered coal which split up easily to sheath-knife and hammer. Every layer of these gave abundant vegetable remains. Most of the bigger leaves were like beech leaves in shape and venation, in size a little smaller than British beech, and the venation much more abundant and finer in character, but distinctly beech-like." I

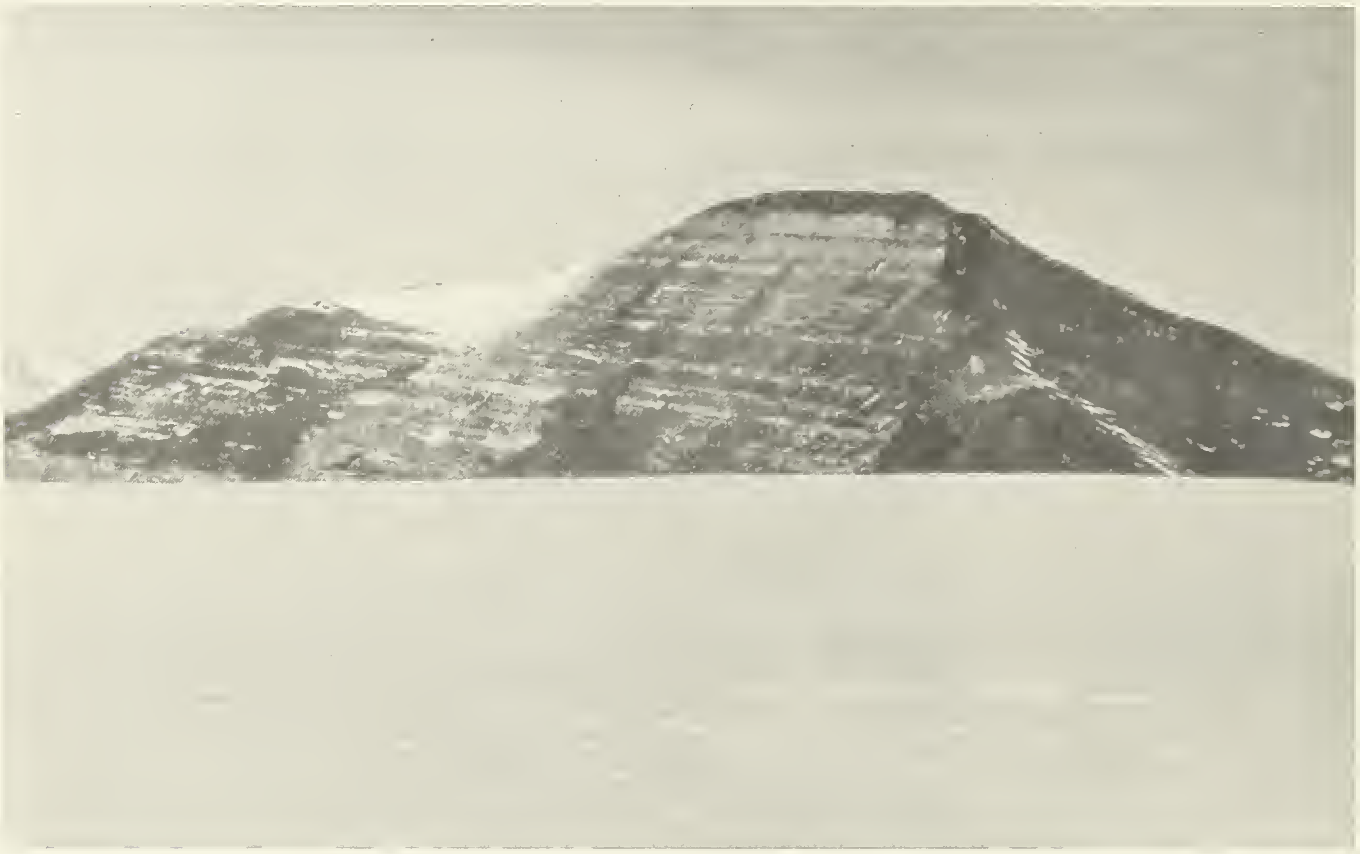

Fig. 5.—Buckley Island; an enlarged view of a portion of the whole shown in Fig. 4. From a photograph by Mr. C. S. Wright.

have not been able to obtain any satisfactory preparations of tissue fragments from the coal, but on the surface of the carbonaceous shale pieces of *Glossopteris*-leaves are clearly shown: these are the beech-like impressions referred to in the diary. The narrow bands of coal interbedded with shale undoubtedly represent débris of drifted vegetation and not the remains of plants *in situ*.

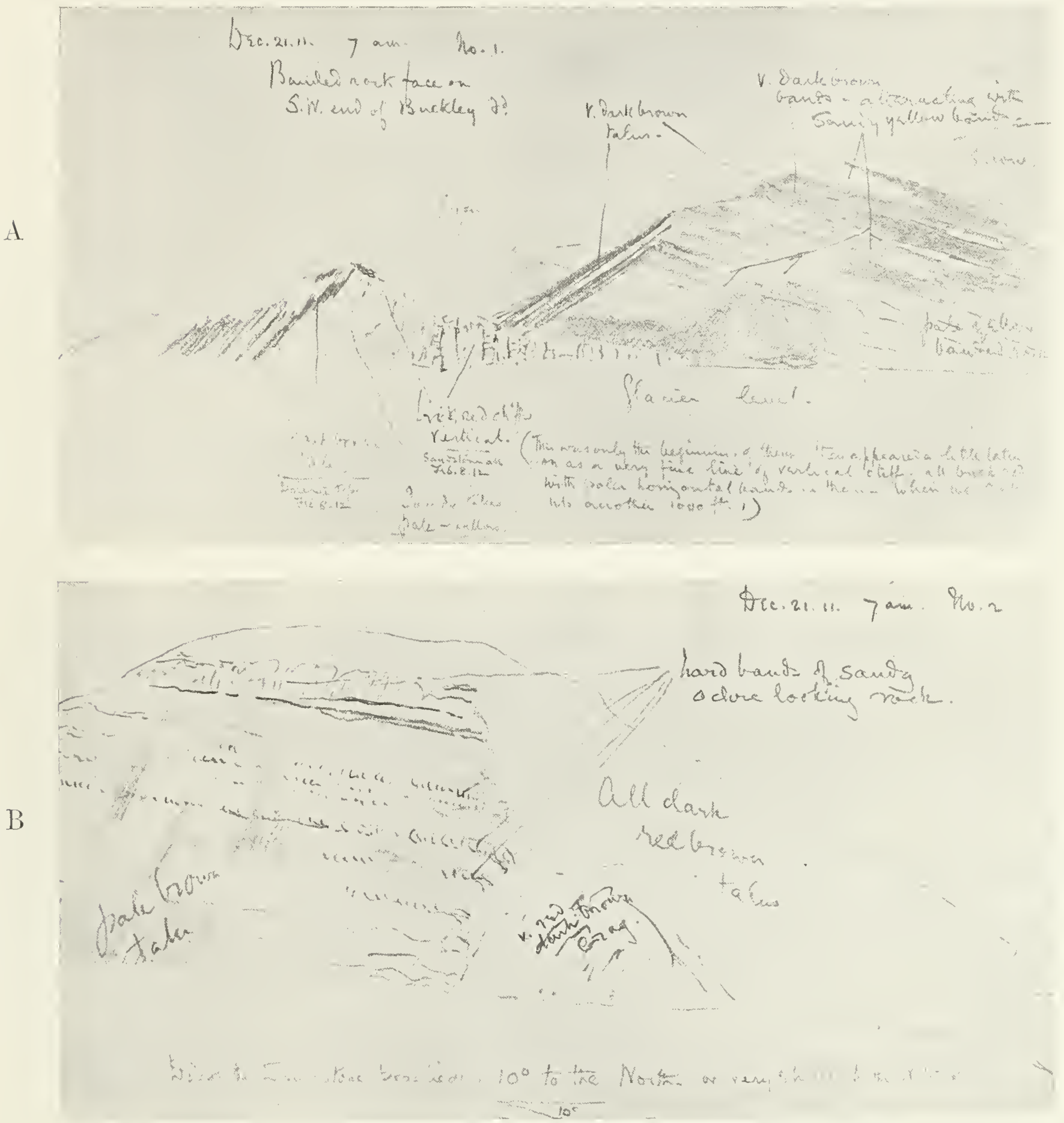
A
Dec. 21. 11. 7 am. No. 1.
Banded rock face on S.W. end of Buckley Id.
V. dark brown talus.
V. dark brown bands – alternating with sandy yellow bands
Glacier level.
Vertical.
Sandstone
pale yellow banded
B
Dec. 21. 11. 7 am. No. 2
hard bands of sandy ochre looking rock.
All dark red brown talus
pale brown talus
V. red dark brown crag.
10° to the North
10°

FIG. 6.—The cliffs of Mount Buckley as seen from the Beardmore Glacier. From sketches made by Dr. Wilson on December 21, 1911, on the outward journey of the Polar party. The strata, with the exception of the highest beds seen in Fig. B, in all probability belong to the Beacon Sandstone series. In the sketch of the S.W. end of the mountain (Fig. A) some of the screes present a deceptive resemblance to inclined strata.

5.—THE BEACON SANDSTONE.

The Beacon Sandstone in which the fossil plants were found, so called from the hills named by Lieut. Armitage the Beacon Heights, plays a very important part in the configuration of the mountains and nunataks of Antarctica. With the exception of the plants and fish-scales obtained by members of Capt. Scott's two expeditions and of Sir Ernest Shackleton's expedition, the strata have afforded no evidence of life. The almost horizontal sandstone occasionally associated with impure coal and carbonaceous shale forms a series of considerable thickness in South Victoria Land. As Dr. G. T. Prior[1] points out in his Report on the rock specimens collected by the First Scott Expedition, the quartz grains of the sandstone have well rounded angles, a feature suggesting the action of sandstorms in a dry climate. Mr. Debenham[2] cites the occurrence of sun-cracks and ripple-marks as additional evidence of semi-arid conditions, though, as he says, the presence of coal indicates "a humid climate and a marshy topography." This dominant Antarctic formation extends from Mt. Nansen (Map A) to at least as far south as latitude 85° S., a distance of 700 miles. In latitude 85° S. the Beacon Sandstone series reaches a thickness of 1,500 feet; 500 feet of sandstone at the top resting on 300 feet of the same material interbedded with shale, and several seams of coal succeeded by 700 feet of more sandstone with large water-worn pebbles in the lower beds.[3] The granites and gneisses from which the material of the Beacon Sandstone was derived were in all probability exposed to the disintegrating action of wind-blown sand in a climate sufficiently mild to permit of the existence of *Glossopteris* and other plants. Fragments of leaves and twigs with larger logs of wood were carried by rivers or marine currents and buried in the barren sand that was being piled up on the floor of an Antarctic sea, to be subsequently uplifted as vast sheets of sedimentary strata, which at a later stage were penetrated by the products of a widespread volcanic activity.

Charred remains of plant-organs and the almost complete obliteration of structure in the pieces of wood collected both from the sandstone and the volcanic tuff, attest the proximity of intrusive sheets; and in some rocks collected by Mr. Debenham and Mr. Priestley the former presence of plants is shown by the abundance of black streaks and occasional patches of graphite, which mark a further stage of metamorphism. The small number of recognisable fossils cannot be accepted as a criterion of the paucity of the vegetation. The piece of rock reproduced in Fig. 8, Pl. II, covered with overlapping fragments of *Glossopteris*-fronds recalls certain beds in South Africa and Australia packed with the same type of leaf; the occurrence of coal-seams and carbonaceous bands favours the view that the wind-swept hills of the Antarctic continent, though perhaps themselves sparsely clad with vegetation, overlooked some sheltered lowlands covered with the gregarious *Glossopteris* and its associates.

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[1] National Antarctic Expedition, 1901–04. Natural History. Vol. I, Geology, p. 134, fig. 71.

[2] Scott's Last Expedition. Vol. II, p. 435.

[3] T. W. Edgeworth David and R. E. Priestley, "Heart of the Antarctic." Vol. II, p. 299.

II. FOSSIL PLANTS FROM GRAHAM LAND AND KERGUELEN ISLAND.

1.—GRAHAM LAND (Map C, lat. 65° S., long. 60°; Map B, P.).

No evidence has so far been discovered of the existence of the *Glossopteris* flora in this southern remnant of a lost continent. In 1904 Prof. Nathorst[1] announced the discovery of a comparatively rich Jurassic flora by members of the Swedish Antarctic Expedition of 1901–03, and the recently published description of the specimens by Dr. Halle[2] demonstrates the remarkable fact that during the Jurassic period vegetation flourished as far south as lat. 63° 15′, characterised by the presence of several species that are widely distributed in Middle Jurassic strata in Europe, North America, India, and the Far East.

From Seymour Island (lat. 64° 16′ S.) the Swedish explorers obtained several Tertiary plants, which have been described by Dr. Dusén[3] and by Dr. Gothan.[4]

2.—KERGUELEN ISLAND (Map C, lat. 50° S., long. 70°; Map B, Q).

The main island and a host of smaller islands consist for the most part of basaltic rocks, and probably represent "the upper portion of a submerged plateau of considerable extent."[5] Fossil wood was found embedded in igneous rock during the visit of the Ross Expedition in 1840, one piece being 7 feet in circumference,[6] and since then additional specimens have been collected. Material brought by Capt. von Schleinitz was described by Goeppert[7] in 1881 as a species of *Araucarites*; the examination of sections cut from a piece of petrified wood in the British Museum, obtained by Sir Joseph Hooker, who accompanied Sir James Ross, enables me to confirm Goeppert's statement as to the occurrence of Araucarian wood. The presence of another type of coniferous wood (*Cupressinoxylon*) has been recorded by Beust[8] and Crié.[9] Precise data as to the age of the plants are lacking, but they are generally assigned to the Tertiary period; the conditions under which the stems are preserved suggest comparison with the preservation of plants in old surface-soils between the sheets of basalt in the volcanic plateau in the north-west of Tertiary Europe. The published photographs and sketches of Kerguelen Island, particularly those in the well-illustrated volume containing an account of the observations made by members of the German South Polar Expedition of 1901–1903,[1] show a close resemblance between the flat-topped basaltic hills of Kerguelen Island and those of South Victoria Land. Though such resemblance is in itself of very little value as a criterion of contemporaneity, it may be that there was an extensive outpouring of volcanic material over an enormous area in the Tertiary period.

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[1] Nathorst (04).

[2] Halle (13).

[3] Dusén (08).

[4] Gothan (08).

[5] Thomson and Murray (85), p. 347.

[6] Ross (47), p. 71.

[7] Goeppert (81); Gothan (08), p. 13; see also Studer (78).

[8] Beust (85), p. 12.

[9] Crié (89), pl. X, figs. 1–6.

III. DESCRIPTION OF SPECIMENS.

1. CARBONISED PIECES OF STEMS. Specimen A; from the Priestley Glacier. Text-figure 1 and Plate I, fig. 1.

This specimen consists of two portions of a carbonised stem in a quartzitic sandstone (text-fig. 1 and fig. 1, Pl. I). The larger of the two pieces is 34 cm. long. and 14 cm. broad; another piece, not reproduced, has a maximum breadth of 17 cm. The substance of the plant occurs in the form of more or less regular rows of square or oblong patches or as longer strips of carbonised tissue embedded in depressions bounded by projecting ridges of the sandstone matrix: the edges of the black patches are for the most part sharp and clean-cut. The breaking up of the material into cubical blocks recalls a log charred by fire, and a probable interpretation of the peculiar method of preservation is that the stem was exposed to the action of volcanic heat. It is noteworthy that the hardness and texture of the rock are also suggestive of the proximity of a lava-flow or intrusive dyke. In the case of a soft stem containing a large amount of water, exposure to the desiccating influence of sun and wind might cause shrinkage and cracking like that shown in Fig. 1, Pl. I; but the more drastic action of heat would probably be necessary to cause the tissues of a tough, woody stem, *e.g.* that of a Conifer, to split both transversely and longitudinally. The state of preservation reminds me of a piece of stem of the large Antarctic alga *Lessonia*, which on drying undergoes considerable contraction, the outer tissue being split into separate blocks by intersecting fissures. The stems of *Lessonia* reach the thickness of a man's thigh, and are usually five to ten feet in length. Sir Joseph Hooker's story[2] of the captain of a brig who employed his crew for two days collecting *Lessonia*-stems that had been washed up on the beach, in the belief that they were logs fit for fuel, gives point to the suggestion that such stems may also in a fossil state be mistaken for trunks of Gymnosperms.

Chemical treatment of the carbonised tissue gave no results; but some of the patches, on magnification, show distinct indications of a longitudinal striation suggestive of woody elements. Although identification of the stems is impossible, the probability is that they are pieces of a well-grown Gymnospermous tree with a comparatively thick and straight stem such as would not be produced in a climate comparable with that in the Antarctic regions at the present day. The occurrence of the broken stem in a sedimentary rock indicates drifting: the boulder in which the fossil was found must have travelled some twenty or thirty miles from the parent rock. How far the wood was carried by currents cannot be determined.

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[1] Drygalski (12).

[2] Hooker (44).

2. CARBONISED WOOD. Specimen B; from the Priestley Glacier. Plate I, fig. 2.

The specimen reproduced natural size in Fig. 2 is one of several pieces of wood discovered on splitting a block of sandstone brought from the moraine on the Priestley Glacier; it is interesting on account of the striking resemblance to freshly burnt wood, a resemblance which supports the comparison made with reference to the larger pieces shown in Fig. 1 from the same rock.

The rock containing specimens A and B is probably derived from the Beacon Sandstone series.

3. PORTION OF A STEM. Specimen C; from the Buckley Island moraine. Plate I, fig. 3.

This is the specimen described by Dr. Wilson as a stem with "cellular structure": the complete fossil has a length of 14 cm. and a breadth of 1·2 cm. All the carbonaceous matter has disappeared except at the edges, where it is left as small patches in depressions bounded by intersecting ridges caused by sand filling up cracks like those, on a larger scale, in specimen A. The rock is probably from the Beacon Sandstone series.

4. FRAGMENT OF WOOD. Specimen D; from Buckley Island. Plate II, figs. 4, 5.

The fragments illustrated by the two sections reproduced in Figs. 4 and 5 are embedded in a piece of siliceous rock from near the top of the Beacon Sandstone. The structure is almost completely obliterated, presumably by the neighbouring dolerite sill; but under a low magnifying power transverse sections of the fragments show closely-arranged darker and lighter lines bent into sharp zigzag folds which are no doubt ghosts of xylem elements, the tissue being replaced by numerous particles of carbon scattered through the siliceous matrix. The fainter traces of structure seen in Fig. 5 point to a further stage of metamorphism than is represented by the section reproduced in Fig. 4. The wood is probably that of a Gymnospermous plant.

A question suggested by the almost complete obliteration of the structural features of the wood and by the presence of the carbon particles, is the relation in time between the burying of the plant fragments in sand and their exposure to heat. The state of the wood suggests that the tissues had not been petrified when it was exposed to heat, but on the other hand wood may be preserved in a carbonised condition for an unlimited time, and if a stem that had already been partially converted into coal were exposed to the influence of igneous intrusions the effect might well be to convert the carbonised tissue into small particles of carbon like those seen in the sections of this specimen.

5. Wood partially converted into Impure Bituminous "Coal." Specimen E; Priestley Glacier. Plate II, figs. 6 and 7.

Several pieces of a dark brown material of low specific gravity were obtained from a block of volcanic tuff on the Priestley Glacier. They consist of very imperfectly preserved and crushed wood of homogeneous structure. The brown walls of the torn tracheids, in places where they are cut obliquely, present an appearance suggestive of scalariform or spiral bands, but this is doubtless due to decay acting along lines determined by the structural features of the membrane. There is no trace of any undoubted pitting. As seen in Fig. 6, the structure in some parts of the section is masked by the presence of opaque bands of a bituminous substance which has filled the lumina of the tracheids. The lighter patches shown in Fig. 6 consist of crushed xylem elements in oblique transverse section occupying the meshes of an irregular recticulum formed by the replacement of the wood by bituminous material. On one side of the section this reticulum passes into more or less parallel tongues of an opaque substance, with little or no trace of woody structure. The enlarged view of a portion of the section reproduced in Fig. 7 shows more clearly the contrast between the two types of preservation. The sections recall preparations of jet[1] from the Liassic rocks of Yorkshire showing similar stages in the obliteration of the structure of a stem.

Some of the lighter veins running through the wood are occupied by small twinned crystals of albite,[2] a result most probably of volcanic action.

Mr. Summers, of Emmanuel College, who kindly examined a piece of this material for me, reports that on heating it gave off thick fumes which formed a sooty deposit on the sides of the crucible and soon broke into flame. After being kept at white heat for twenty minutes, a piece of ash was left approximately equal in size to the original specimen. The ash, which was not acted upon by acids, formed 34 per cent. of the whole.

Though identification is impossible, the wood is probably that of a Gymnosperm.

6. Specimen F. Buckley Island.

Several pieces of greenish grit contain fragments of carbonised plants, but none of them can be identified.

7. Specimen G. Buckley Island.

The calcareous sandstone described by Dr. Wilson in his notes on the Buckley Nunatak as limestone, contains pieces of wood which, though not determinable, afford additional evidence of the existence of arborescent plants when the Beacon Sandstone was deposited.

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[1] Compare, especially Pl. VIII, figs. 1–7, Seward (04^2).

[2] I am indebted to Mr. Harker and Mr. Debenham for identifying the crystals.

Glossopteris indica Schimp. Plate II, fig. 8 ; Plate III, figs. 9, 9A.

The best specimen obtained by Dr. Wilson from Buckley Island is that reproduced natural size in Fig. 8, Pl. II. On both sides of the rock (a hard siliceous shale) are several fragments of *Glossopteris*-fronds associated with broken pieces of rachises and a broader axis that is described below as possibly a portion of *Vertebraria* (Fig. 8, v, Pl. II ; Figs. 10, 10A, Pl. III.). None of the fragments show either the base or apex of the lamina, but the venation is clearly preserved. The best piece of lamina is reproduced in Fig. 9 from a careful drawing by Mr. Brock. The secondary veins are given off at an angle of 50° : in the lower part of their course they form elongated polygonal meshes, while further from the rachis the oblique anastomoses are fewer and further apart, the veins pursuing a regular parallel course about ·5 mm. apart.

There is a very close resemblance between the venation of this piece of leaf and that of the type-specimen of *Glossopteris indica* figured by Zeiller,[1] which, in my opinion, leaves no doubt as to their specific identity. The distinction between *Glossopteris Browniana* Brongn. and *G. indica* Schimp. is by no means well-marked in all cases ; it depends in part on the form of the frond as a whole, but chiefly on the form of the reticulum made by the anastomosing veins. In *Glossopteris Browniana* the longer sides of the areolae tend to be more curved than in *G. indica*, which is characterised by elongated meshes with parallel sides, though near the midrib the meshes are often broader and identical with those of *G. Browniana*. It is, however, difficult, especially in dealing with small pieces, to recognise any trustworthy distinguishing feature. In view of the range of variation in the arrangement of the anastomosing veins even in a single leaf, and still more in different leaves that cannot be specifically separated, I formerly[2] adopted the plan of using the species-names *indica* and *angustifolia* as variety-designations, but Zeiller's careful investigation of the type-specimens in Paris has supplied more satisfactory grounds for retaining the names *Browniana*, *indica*, and *angustifolia* as specific designations.

Vertebraria sp. Plate II, fig. 8, v. ; Plate III, figs. 10, 10A.

The largest piece of axis, 5·5 mm. broad, preserved on the slab shown in Fig. 8, Pl. II, is represented in Fig. 10. The surface is uneven and characterised by raised and depressed portions suggesting comparison with the peculiar features of *Vertebraria* as described by many authors. Specimens figured by Zeiller,[3] from South Africa, bear a distinct resemblance to the Antarctic fragment. The roughly parallel and faintly-marked ridges seen in the enlarged drawing, Fig. 10A, are similar to those on the rachis shown in Fig. 9A. The evidence, though far from being decisive, would seem to point to the identification of this fragment as a piece of *Vertebraria*, the name given to a type of axial organ very widely associated with *Glossopteris*-leaves which Zeiller and Oldham were the first to recognise as the stem of *Glossopteris*.[1] We have still but little information as to the nature of *Vertebraria*, and it is significant that in some cases in which *Glossopteris*-leaves occur attached to a stem the surface-features are not those of a typical *Vertebraria*.[2]

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[1] Zeiller (96), figs. 11, 12, p. 367 ; see also Zeiller (02).

[2] Seward and Leslie (08).

[3] Zeiller (96), pl. xv.

? *Vertebraria* sp. Plate III, fig. 15.

The block of carbonised tissue, 3 cm. long, from a piece of coaly shale from Buckley Island, represented in Fig. 15, may be a fragment of a stouter *Vertebraria*, but it is too small and imperfect to be determined with any degree of confidence. The surface is slightly convex, characterised by the fine longitudinal striation of woody tissue and by numerous transverse wrinklings in the form of minute interrupted ridges. The lower edge is bounded by a fairly sharp line which gives the impression of a natural groove or division running through the tissue. The narrower piece shown at the upper end of the drawing is separated by an accidental fissure from the broader portion. The evidence in support of a reference to *Vertebraria*, chiefly derived from the clean-cut lower edge, is, however, very slight.

Glossopteris indica Schimp. var. *Wilsoni* nov. Plate III, figs. 11–14.

This designation is suggested for several fragments of *Glossopteris*-leaves from Buckley Island with the parallel venation of *G. indica*, but characterised by the rarity or almost complete absence of oblique connections between the secondary veins.

One of the largest specimens is represented in Figs. 11, 11A. The veins, approximately ·5 mm. apart, are occasionally connected by oblique anastomoses, but for the most part they pursue a separate and parallel course. The preservation is far from good. In the paucity of connecting veins this and other fragments agree with some Indian specimens of *Glossopteris indica* described by Zeiller,[3] from the Karharbari beds, and with the South African form named *G. angustifolia* var. *taeniopteroides*.[4] Further reference is made to the occurrence of *Glossopteris*-fronds with few anastomoses in the section of this paper dealing with New Zealand. Although we have no means of knowing whether the leaves of a single plant differed as widely in their venation as do the specimens represented in Figs. 9, 11–14, it would seem worth while to emphasise the departure from the normal by the employment of a distinctive epithet.

The fragment shown in Figs. 12, 12A illustrates a slightly further stage in the disappearance of anastomosing veins, and in that reproduced in Figs. 13, 13A the simplification of the venation is carried further. As seen in the enlarged drawing,

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[1] For further information see Arber (05), pp. 93 *et seq.*; Seward (10), pp. 503 *et seq.*

[2] Etheridge (94); Seward *loc. cit*, fig. 339, p. 504.

[3] Zeiller (02).

[4] Seward and Leslie (08), p. 113; see also Seward (10), p. 508.

Fig. 13A, some of the secondary veins are forked near the midrib, but I have not been able to detect any absolutely certain case of cross-connections. In view of the general identity of this fragment with the others, I have no hesitation in referring it to *Glossopteris* rather than to *Taeniopteris*.

Figs. 14, 14A represent a small piece of lamina preserved on the calcareous sandstone from Buckley Island: the veins are rather closer than in other fragments and a cross-connection occurs here and there.

? Scale-leaf of Glossopteris. Plate III, figs. 17, 17A.

A very imperfectly preserved and obscure impression on a piece of calcareous sandstone, represented in Fig. 17, shows faint and slender veins spreading from the narrow base of what may be a scale-leaf of *Glossopteris*. Scale-leaves of various sizes have been described from many localities, and their occurrence is to be expected where the foliage leaves are preserved.

Indeterminable fragment: ? Scale-leaf of *Glossopteris*. Plate III, figs. 16, 16A.

This torn fragment, 7·5 mm. long, on calcareous sandstone, at first sight suggested a small pinnule of a *Thinnfeldia*, but it is much more probable that this resemblance is accidental and that the specimen is a portion of a small scale-leaf.

Antarcticoxylon Priestleyi gen. et spec. nov. Text-figure 3; Plates IV–VIII.

The type-specimen was found by Mr. Priestley in a boulder, presumably derived from the Upper Beacon Sandstone, on the Priestley Glacier: it is a portion of a dark brown silicified stem about 3 inches in diameter and a foot long. It was impossible, owing to the cracked and brittle condition of the specimen, to extract it whole, but several blocks were obtained from which sections have been prepared after treatment with some hardening solution to prevent splitting into smaller fragments.[1] The preservation is, unfortunately, far from satisfactory, especially in the pith and peri-medullary region. The anatomical features afford some evidence of affinity with the Cordaitales and Araucarineae, but in view of the presence of certain morphological characters which, so far as I know, have not been previously recognised in any fossil plant, I have instituted a new generic name.

There are no tissues preserved external to the wood, and it is impossible to determine what proportion of the whole thickness of the secondary xylem is represented. The stem had suffered some decay before petrifaction, though no traces of fungal hyphae have been discovered: the difficulty of interpretation has been greatly increased not only by the destruction of the tissues in places that are particularly important from a diagnostic point of view, but by the displacement and tearing of the leaf-traces and other portions of the stem.

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[1] I am indebted to Dr. Krantz of Bonn for the careful preparation at short notice of some of the sections of this stem.

An examination of the transverse sections shows that the elliptical form is the result of crushing: the rows of tracheids composing the homogeneous wood have been in places pressed into zigzag folds, and further evidence of compression is afforded by the sinuous course of the leaf-traces, as seen in Figs. 21–25, Pl. IV. The same type of folding is seen in the much more imperfectly preserved wood from Buckley Island represented in Figs. 4 and 5, Pl. II. As Gothan[1] has suggested, this zigzag form of folding may be due, in part at least, to the difference in resisting power between the spring and summer tracheids. Rings of growth are clearly marked, as shown in Figs. 23, 24, Pl. IV; but owing to the crushed condition of the tissue the contrast between the two parts of each ring is by no means sharply defined when the sections are seen under the microscope. There is, however, no doubt as to the presence of rings of growth: these vary from rather less than 1 mm. to more than 2 mm. in breadth. A portion of one of the broader rings is shown in Fig. 26, Pl. V: in this region, as in most other parts of the wood, the individual elements are considerably flattened and distorted, and the contrast between medullary rays and tracheids is not obvious under a low power. One of the few places where the tracheids have been comparatively little crushed is shown in Fig. 28, Pl. V: the light radial bands mark the position of the medullary rays. In one section (section N) some of the xylem elements have thick walls, a feature due, at least in part, to the deposition of mineral substance against the original membrane.

The centre of the stem is occupied by a lighter elliptical area, approximately 7 mm. long by 2 mm. broad, which at first sight suggests a fairly large pith (Figs. 23, 24, Pl. IV.; Fig. 46, Pl. VIII). It is, however, probable that the actual pith was not more than 2–3 mm. in diameter. The dark patches of tissue near the inner edge of the secondary wood in Fig. 24, Pl. IV, and Fig. 46, Pl. VIII, consist of broken portions of a cylinder of narrow spiral and scalariform tracheids, and internal to these patches of primary xylem there are broken and crushed portions of parenchymatous tissue associated with interrupted dark bands arranged in horizontal series and extending across part of the pith (Fig. 35, Pl. VI; Fig. 41, Pl. VII). The imperfectly preserved parenchyma is represented in some places by rather large cells characterised by their irregularly branched form (Fig. 39, Pl. VII; Fig. 45*, Pl. VIII) indicating lacunar tissue. The dark patch *S*, close to the branched cells seen in Fig. 45*, is part of one of the patches of secretory sacs in the pith. The pith probably consisted of lacunar tissue occupying regions partially separated from one another by horizontal rows of cells containing secreted substance. In some places cell-membranes can be seen close to the edges of the opaque substance of the horizontal bands. It is impossible to say whether the pith was originally solid or discoid: the dark bands bear a resemblance to those in the much larger discoid pith of *Mesoxylon*.[2] Owing to its imperfect preservation no definite statement can be made with regard to the structure of the peri-medullary zone:

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[1] Gothan (06).

[2] Maslen (11); Scott (12).

at the edge of the pith there was a fairly broad zone of primary xylem elements characterised by spiral and scalariform bands and by their relatively narrow diameter. Some of the spiral tracheids are seen in Figs. 30, 31, Pl. V. There is a sharply defined distinction between the secondary xylem as a whole and the xylem which occurs as broken pieces of tissue at the periphery of the pith. The latter, which is spoken of as primary xylem, is characterised by the narrower diameter of its tracheids and by spiral and scalariform pitting in place of bordered pits such as occur on the secondary elements. Differences in the state of preservation of the two types of xylem also suggest that the primary tissue is more delicate than the main mass of secondary wood. It is this inner xylem that constitutes the leaf-traces, as is clearly shown by the identity in structure of the xylem strands met with in their course through the wood and the primary xylem at the edge of the pith (*cf.* Figs. 34, 37, 38, 47, etc., and Figs. 41, 44). The tissue shown at the periphery of the pith in Fig. 49, Pl. VIII, presents a superficial resemblance to a leaf-trace of *Mesoxylon*, but the apparently centripetal wood owes its position to displacement of some of the centrifugal secondary tracheids. The small tracheids at *px* may be a protoxylem strand. Fig. 44 represents another portion of the peri-medullary zone where the rows of centrifugal elements show a similar tendency to a convergent disposition. In this section one might suppose the protoxylem to be situated at *a*, but there is no proof that this is the case. It is more probable that the protoxylem was on the inner edge of the crushed tissue *x'*. This innermost xylem, as it appears in some sections, apparently—though I believe not in reality—internal to the protoxylem, presents some resemblance to the radially disposed cells that occasionally constitute the sheath on the inner margin of a leaf-trace in *Mesoxylon Lomaxii*[1]; but in *Mesoxylon* the sheath consists of short cells and not of long tracheids, and it is developed internally to the centripetal xylem of the trace. In *Antarcticoxylon* the centrifugal nature of the primary xylem is indicated by the occasional occurrence at the inner edge of the tissue, as seen in some longitudinal sections of the pith, of tracheids in which the spiral bands are most widely separated. Although accurate description and confident interpretation are hardly possible, it is clear that in *Antarcticoxylon* there was a development of comparatively delicate tissue on the inner border of the xylem cylinder. This tissue furnished the xylem of the leaf-traces; it occurs in the peri-medullary region in transverse and in oblique longitudinal section, though to what extent this is due to tearing and displacement cannot be determined. Such evidence as can be obtained from the incomplete material seems to favour the view that the innermost xylem is centrifugal in its development.

A characteristic feature of the primary wood in the peri-medullary region, as also in the leaf-traces on their way through the secondary xylem, is the presence of short and broad tracheids with imperfectly preserved reticulate thickening bands in close connection with the innermost spiral tracheids of the primary xylem. A few of these isodiametric elements are seen in Fig. 43, Pl. VII, and others occur at *t* in Fig. 34, Pl. VI, close to the junction of a leaf-trace with the secondary wood. These short tracheids, identical with certain types of transfusion elements, may represent centripetal xylem, and may be compared with the much larger and more abundantly developed storage tracheids in the Carboniferous stem *Megaloxylon*.[1] Similar cells are mentioned by Scott in the sheath of *Mesoxylon Lomaxii*.[2]

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[1] Scott (12), p. 1015, pl. lxxxvii, fig. 5.

The secondary xylem consists exclusively of tracheids and narrow medullary rays; there are no resin-ducts or xylem-parenchyma cells. Except in a few places there are no signs of pits on the xylem elements; but the fact that when the pits are preserved they occur either as a single row of contiguous and partially flattened pits or, occasionally, as a double row of alternate polygonal pits (Figs. 33, 36, Pl. VI), justifies the conclusion that the tracheids had bordered pits of the Araucarian type on their radial walls. No tracheids have been found with more than two rows of pits, a feature in which the stem agrees more closely with recent Araucarineae than with the Palaeozoic types. In no case have I been able to detect more than the outer border of the pits. The medullary rays are nearly always uniseriate (Fig. 29, Pl. V), but in one place (Fig. 32, Pl. VI) a double ray was noticed. The rays are from one to twenty-four cells in depth; the walls are thin, a feature that may be to some extent due to decay, and the vertical walls tend to be straight rather than oblique.

An interesting feature seen in the transverse sections is shown in Figs. 21-23, 25, Pl. IV, namely, the occurrence of light bands concentric with the rings of growth (Figs. 18, 22, 23*b*), which become broader near the long axis of the stem, where they are slightly folded by compression. These bands gradually decrease in breadth when traced round the circumference, and eventually die out. In the narrower portions the light bands are clearly due to the partial destruction of the secondary xylem, which is replaced by mineral substance, and in the broader parts (Fig. 25*b*, Pl. IV; Fig. 27, Pl. V; Fig. 48*b*, Pl. VIII) there are occasional rows of tracheids connecting the two sides of the gap. But there are indications that these bands are not wholly due to the partial destruction of the secondary xylem. In some places crushed parenchymatous cells occur in association with the disorganised and thin-walled tracheids, and narrow spiral tracheids identical with those of the leaf-traces were found in a few of the broad light bands. The occasional occurrence of tracheids belonging to leaf-traces is probably accidental. The presence of parenchyma may point to the formation of wound-tissue conceivably as the result of compression of the stem before the death of the medullary cells from which the parenchyma may have been derived. There are, however, no signs of resin or secreted substance as one would expect in traumatically produced intra-xylar tissue, such as Conwentz[3] and other authors[4] have described. Comparison may also be made with Nördlinger's medullary spots formed by local hypertrophy of the medullary rays of some dicotyledons and conifers, which results in the development of elongated areas of parenchyma, not infrequently in the middle of an annual ring, and sometimes extending through 90° or more.[1] As seen in Figs. 18, 21, 23, 25, Pl. IV, leaf-traces occasionally cross these broad concentric bands, and at the point of intersection portions of the outgoing leaf-trace might easily be displaced on the decay of the softer tissue and so introduced into one of the spaces formed in the secondary wood. Fig. 18 shows part of the horizontal face of a piece of stem on which two leaf-traces, *aa*, intersect a light band, *bb*. Fig. 18A shows the same piece in side-view; the two traces are seen as narrowed tapered gaps in the wood filled with mineral matter, while below these are two larger lenticular areas of the same type, each of which decreases gradually in breadth above and below the widest part. In the photograph of the complete specimen shown in Text-fig. 3 several lenticular light areas are clearly shown, and their disposition is spiral. On the side of the piece of stem, drawn natural size, in Fig. 19 there are two broad strips like those in Fig. 18A, and these correspond to the two leaf-trace regions seen at *a*, *a* in Fig. 23. The leaf-traces appear in the transverse sections, reproduced in Figs. 22 and 23, as light radial bands, some of which pursue a sinuous course in consequence of the pressure to which the stem was exposed. The two pairs of traces seen at *l′* Fig. 22 produce the impression of strands of xylem given off at the same level, but they are in reality members of a spiral series, as is clearly shown in Text-fig. 3 and in Fig. 18A. As each leaf-trace in its outward course through the secondary wood occupies a vertical area of considerable extent, the same trace would be cut through in several transverse sections. The enlarged portion of Fig. 23, reproduced in Fig. 24, shows three leaf-traces on one side of the pith and two on the other. In Fig. 25 a trace is cut through in an obliquely vertical direction. In the inner part of its course at *l* it has almost disappeared from view, becoming more apparent as it ascends towards *a*, where it intersects a broad light band *b*, *b*. It is clear that the great breadth of the lenticular areas seen in Figs. 18 and 19 and in Text-fig. 3 is due to decay. In the more external part of their course, where the position of the leaf-traces is marked by the broad areas, these are largely occupied by infiltrated mineral matter in which are embedded fragments of xylem strands and some parenchyma. Fig. 20, Pl. IV, shows, natural size, a longitudinal section of the secondary wood and pith (*p*); the large clear spaces are occupied by a siliceous matrix containing parenchyma and curved strands of xylem; at *d* and *e* the narrow spiral elements are in organic connection with the secondary wood at the lower and upper ends, respectively, of the gaps. The section is faulted along the line *c*. Fig. 34, Pl. VI, shows the connection of the trace at *e* in Fig. 20 with the secondary xylem, and in Fig. 37, Pl. VI, and Fig. 40, Pl. VII, are shown the twisted and forked traces in the broad spaces in the secondary wood in another section (F.). The darker edges of the section are occupied by secondary xylem, and in the centre is a broad leaf-trace with the marginal tracheids on the left-hand side bent into loops and folds enclosing small groups of parenchyma. In the lower part of the section at *t* are several short isodiametric tracheids: the lighter portions between the trace and the secondary xylem are occupied by the remains of parenchyma. The strand shown in Fig. 38, Pl. VII, partly in transverse and partly in oblique vertical section, is situated at *l''* in Fig. 21, Pl. IV: the whole trace has a triangular form, and at the apex the tracheids appear to lose their radial arrangement, though this may be the result of distortion: the spiral and scalariform pitting is seen on the tracheids curving downwards on the left-hand side. Figs. 37 and 40, Pls. VI and VII, illustrate the curved and occasionally branched form of the traces in their obliquely ascending course, and these sections also show that there must have been a considerable amount of parenchyma accompanying the xylem strands in their course through the secondary wood (Fig. 37, *pr.*). The apparently double trace seen in Fig. 40, Pl. VII, is probably a single leaf-trace that has become stretched, as the result of the increasing diameter of the stem, and divided into separate strands which tend to form an irregular reticulum joined here and there to the neighbouring secondary xylem. The strand seen in Fig. 41 occurs in the pith in association with some of the dark horizontal bands, and on the left side some of its tracheids have formed an irregular reticulum. The torn and imperfectly preserved trace shown in Fig. 42 lies at *f* in the gap seen in Fig. 23.

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[1] Seward (99). [2] Scott (12). [3] Conwentz (90), pl. VI. [4] *e.g.* Jeffrey (06).

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[1] de Bary (84), p. 492. I am indebted to Mr. R. C. McLean for calling my attention to this reference.

Although the structure of the leaf-traces cannot be definitely determined, it would seem that each trace passed into the peri-medullary zone as a single strand of relatively large size composed of spiral and scalariform tracheids narrower than the secondary xylem elements. The traces during their outward course were enclosed by some parenchymatous tissue continuous with that in the pith, and the inner spiral tracheids of the trace were connected with some isodiametric reticulate elements (Fig. 43, Pl. VII). The outgoing strands of xylem are, I believe, all leaf-traces and not branches; the fact that they consist wholly of spiral and scalariform tracheids, and do not include elements with bordered pits, is in favour of this interpretation; moreover, if they were branches, one would expect to find associated with them some of the dark secretory sacs from the pith. The dimensions of the leaf-traces point to leaves of a fairly large size, but we have no other evidence as to the form of the appendages borne by the stem.

In the structure of the secondary wood *Antarcticoxylon* agrees on the whole with an Araucarian stem: the broad zone of xylem, composed of spiral and scalariform tracheids at the edge of the pith, is a feature common to *Mesoxylon* and *Cordaites*, and shared by *Araucaria*. There is no evidence in *Antarcticoxylon* of the occurrence of double leaf-traces such as characterise certain Cordaitalean genera and some existing members of the Araucarineae. The features, so far as it has been possible to interpret them, lead me to the conclusion that in *Antarcticoxylon* we have a distinct type of Gymnospermous stem; despite the imperfect state of preservation the evidence furnished by the series of photographs and by such description as I have been able to give, shows that Mr. Priestley's discovery is one of considerable botanical interest.

Pityosporites antarcticus gen. et spec. nov. Plate VIII, fig. 45.

In the course of my examination of the sections of *Antarcticoxylon* I found two small bodies, the best of which is reproduced in Fig. 45, lying in the siliceous matrix filling spaces in the partially decayed stem. The resemblance of the one shown in the figure to a winged microspore of *Pinus* and other Abietineae is too close to be explained by any accidental similarity of a crushed parenchymatous cell: the figured spore, ·08 mm. long, was found at *s*, close to one end of the pith represented in Fig. 46, just beyond the left-hand edge of the photograph. The central part of the spore is bounded by a comparatively thick wall, and on each side a portion of the membrane is expanded into a bladder characterised by a fine surface-reticulum as in recent pollen-grains. A pollen-grain of *Pinus silvestris* has a length of 0·075 mm., while the spores of *Abies alba* are 0·130 mm. in length:[1] some very similar spores from Jurassic rocks in Franz Josef Land which I measured have a length of 0·09 mm. The Franz Josef Land spores were first recorded by Graf zu Solms-Laubach.[2] Nathorst[3] has described some winged spores from the Lower Jurassic beds of Hör, in Scania, that have a length of 0·10–0·108 mm. It is very unlikely that the spores have any connection with the stem with which they are associated, but their presence is of considerable interest as affording some evidence of the existence of an Abietineous Conifer. Although the possession of bladder-like extensions of the exine is not a feature confined to the Abietineae, the Antarctic spore bears a much closer resemblance to those of *Pinus*, *Abies* and other allied genera than it does to the winged pollen-grains of Conifers belonging to the Podocarpineae: the probability is that it belonged to some Abietineous species, though this cannot be definitely asserted.

The generic designation *Pityosporites* is proposed for winged spores agreeing in form and size with those of recent Abietineous genera.

The occurrence of this type of spore in a stem from a boulder on the Priestley Glacier suggests two important considerations: the probability that the upper part of the Beacon Sandstone from which the boulder is believed to have been derived is not older than Lower Mesozoic, *e.g.* Rhaetic, and the possibility that an Abietineous genus was evolved on the Antarctic continent. Winged seeds similar to those of some Recent Abietineae have been described by Nathorst from the Rhaetic series of Scania, but I am not aware of any records of spores of the *Pityosporites*-type from rocks older than the Lower Jurassic. It has often been assumed that the Abietineae, the dominant family of Conifers in the northern hemisphere, were evolved on a northern continent; but the discovery of the spore shown in Fig. 45 serves as a warning against conclusions based to a large extent upon the facts of present-day geographical distribution, and upon data derived from a study of fossil floras most of which are from countries north of the equator.

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[1] Kirchner, Loew, and Schröter (06), pp. 97, 199.

[2] Solms-Laubach (04), p. 11.

[3] Nathorst (08), pl. II, figs. 53–55.

As I have already admitted, the presence of these two spores does not prove the presence on the Antarctic continent of an Abietineous Conifer, though it affords an argument in support of the opinion that a member of the Abietineae was a contemporary of *Antarcticoxylon*, possibly in Lower Mesozoic days, in Antarctica. On geographical grounds it would seem more probable that the spores belonged to some plant allied to *Podocarpus*, *Dacrydium* or *Microcachrys*,[1] genera possessing winged pollen and at the present day characteristic of the southern hemisphere.

IV. THE ANTARCTIC PLANTS AS EVIDENCE OF GEOLOGICAL AGE.

1.—THE PLANTS FROM THE PRIESTLEY GLACIER.

The boulders in which the specimens were found are believed to have come from the upper portion of the Beacon Sandstone series. The carbonised impressions are valueless as tests of age. The stem described as *Antarcticoxylon Priestleyi* agrees in some respects with recent Araucarineae as with some genera of Cordaitales from Upper Palaeozoic strata: it does not afford any very satisfactory evidence of geological horizon, but its presence is consistent with either an Upper Palaeozoic or Lower Mesozoic position. The pollen-grains (*Pityosporites antarcticus*) found in some decayed portions of the *Antarcticoxylon*-stem point rather to a Mesozoic than to a Palaeozoic horizon. Assuming that the spores belonged to some member of the Abietineae, a family that has not been proved to occur in any Palaeozoic flora, it is probable that the upper part of the Beacon Sandstone is not older than the Rhaetic, or even the Liassic period. A similar conclusion applies with even greater force if we regard the spore as evidence of the existence of a Conifer belonging to the Podocarpineae, a family of which we have very meagre and unsatisfactory geological records. It is, however, possible that the spore reproduced in Fig. 45 belonged to some Palaeozoic plant which was not necessarily a member of the Abietineae.

So far as *Pityosporites* is concerned there is obviously no reason why the rock should not be of any age, from, say, the latter part of the Trias upwards. There is, moreover, not sufficient reason for asserting that *Antarcticoxylon* could not have come from beds higher than the Jurassic.

2.—THE BUCKLEY ISLAND PLANTS.

Although *Glossopteris* has been stated to occur in Queensland in beds assigned to the Cretaceous system,[2] the evidence available from all sources justifies the statement that the genus ranges from the Upper Carboniferous or Lower Permian rocks to the Rhaetic period. It is, however, not improbable that *Glossopteris* appeared on the Antarctic continent earlier than in other parts of the southern province. The species

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[1] For figures of Podocarpineous pollen, see Jeffrey and Chrysler (07); Young (07); and Thomson (09).

[2] For references, see Arber (05), p. lviii.

Glossopteris indica has a wide geographical and geological range, its highest horizon being represented by the Rhaetic beds of Tonkin, and its northerly limit of distribution by the Permian strata in the valley of the Dwina river. It is clear that the occurrence of this type in Antarctica does not afford any conclusive evidence of precise geological horizon, but the fact that *Glossopteris*-leaves are abundant in the Buckley Island beds, and that they are not associated with impressions of other plants, renders it probable that the Rhaetic period may be excluded from the choice of possibilities. The probability is that the beds are Permo-Carboniferous in age; whether occupying a higher or lower horizon in the series cannot be definitely asserted. Even granting that *Glossopteris* is in origin an Antarctic genus, and that it lived on the Polar continent before it spread to other lands, there is no reason to assume that it did not persist in the country of its birth to later geological periods.

V. GENERAL CONSIDERATIONS SUGGESTED BY THE OCCURRENCE OF GLOSSOPTERIS IN ANTARCTICA.

1.—THE WIDE DISTRIBUTION AND COMPARATIVE UNIFORMITY OF LOWER CARBONIFEROUS AND DEVONIAN FLORAS.

Our knowledge of Devonian floras is still very meagre, but so far as can be ascertained from available data there was a close resemblance between Upper Devonian and Lower Carboniferous vegetation, and such records as there are afford no indication of any regional differentiation. From Spitzbergen (Map B, 4) a few Devonian plants are recorded, and a larger number of Lower Carboniferous species.[1] Similar Devonian types have been found in Bear Island and Ellesmere Land[2] (Map B, 2): remains of Devonian plants have recently been described by Nathorst from Norway,[3] and Lower Carboniferous species are known from North-East Greenland[4] (Map B, 3). This older Carboniferous and Devonian vegetation extended over a large part of Europe, its western limit being represented by the plant-beds of the Kiltorkan grits in Ireland, which contain species identical with those from the Arctic regions. Evidence of the existence of the same type of vegetation is afforded by collections from North and South America, from South Africa, Australia, and elsewhere:[5] from one end of the world to the other we have proof of a uniform type of flora characterised by representatives of *Lepidodendron*, *Bothrodendron*, *Archaeocalamites*, *Rhacopteris*, *Archaeopteris*, and other genera.

It was in the latter part of the Carboniferous era that forces came into action which led to a differentiation of the world's vegetation into two botanical provinces. In the northern hemisphere, using the term in a wide sense without regard to exceptions, the appearance of many new forms added richness to the flora that has left abundant remains in the coal-fields of Europe and North America, a flora that extended into North Africa and to south-east China. Greenland may be a remnant of part of the continent (Atlantis) which was the home of this northern flora. The southern flora is preserved in the Permo-Carboniferous beds of India, South Africa, Australia and Tasmania, and South America.

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[1] Nathorst (94); (10). [2] Nathorst (02); (04^2). [3] Nathorst (13). [4] Nathorst (11).

[5] For descriptions of Lower Carboniferous and Devonian plants from the southern hemisphere, see Feistmantel (90); Szajnocha (91); Jack and Etheridge (92); Kurtz (94); Seward (03), and other authors.

2.—THE NORTHERN BOTANICAL PROVINCE: UPPER CARBONIFEROUS VEGETATION AND CLIMATIC CONDITIONS.

In the northern hemisphere a marine transgression on an extensive scale followed the Devonian period, and of this the most striking evidence is afforded by the Carboniferous Limestone that extends from the western edge of Europe beyond the Ural Mountains into Asia and the Far East; to Spitzbergen and the Arctic regions and over a wide area in North America; "as Greenland on the one hand, so the Indian peninsula on the other, projects into the ocean which covers the subsided table-lands."[1] The deposition of clastic material marked a later phase of the Carboniferous era, and, later still, the intercalation of freshwater sediments and seams of coal points to a period of long duration characterised by broad land-masses or island-studded lagoons and marshy swamps supporting a vegetation rich in species and remarkably uniform in its general features over a large part of the earth's surface. This Upper Carboniferous flora persisted with little change into the succeeding Permian period.

The Permo-Carboniferous vegetation, as shown in the sketch-map B, ranged over a considerable area in North America and in the Old World. It is hardly necessary to point out that the boundaries of the regions occupied by the plant-bearing strata, the majority of which belong to the latter part of the Carboniferous period, are drawn on a liberal scale. The map is intended to convey a general idea of the main phytogeographical features in a broad sense, as it is with general considerations and not with details that we are at present concerned. The similarity between the plants from North America and Europe points to a similarity of conditions, as is also shown by an agreement in lithological features. There is evidence that the Carboniferous plants penetrated to Banks Land and other localities within the Arctic circle (Map B, 1, 2)[2]. In Nova Zembla (Map B, 5) plants have been found in association with *Productus* and *Spirifer*. From the vast coal-fields of China many European species have been described by Schenk[3] and other writers: Zeiller[4] has more recently described species of *Lepidodendron* and other Carboniferous types from the province of Chansi, and Zalessky[5] records Carboniferous species from Manchuria, including *Lepidodendron*, *Sphenophyllum*, *Cordaites*, and other genera.

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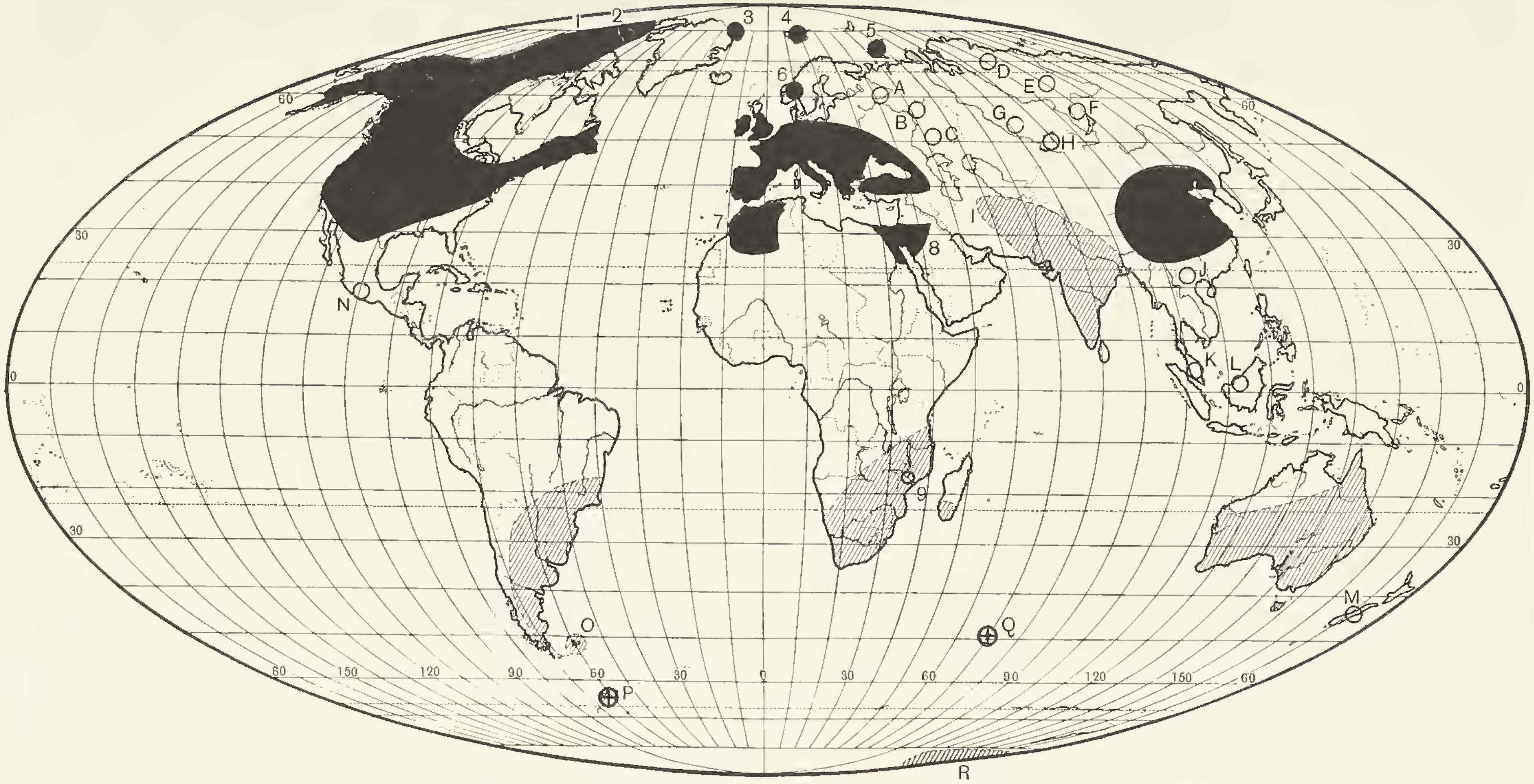
[1] Suess (06), p. 252; (08), p. 19.

[2] Heer (68); Nathorst (10^2).

[3] Schenk (83); Krasser (00), *etc.*

[4] Zeiller (01); see also Abbado (00).

[5] Zalessky (05).



Map B.—The areas shown in solid black represent approximately the geographical distribution of Permo-Carboniferous and, in a few cases, Devonian floras in the northern hemisphere. References to the numbers are given in the text. The areas with oblique lines represent approximately the geographical range of the *Glossopteris* flora. The circles A–H show the position of localities, in Russia and in North and Central Asia, where floras have been found showing some admixture of southern types with northern plant-associations. The circles J and M denote Rhaetic floras in Tonkin and New Zealand respectively, which exhibit points of contact with the older *Glossopteris* flora: the circles K and L indicate localities, in the Malay Peninsula and Borneo, where Lower Gondwana beds are said to occur. P and Q show respectively the position of Graham Land and Kerguelen Island.

Carboniferous plants and marine shells have been found at several localities in North Africa from Morocco to the Sinai peninsula (Map B, 7, 8). The presence of many European species, as stated by Prof. Zeiller,[1] points to the existence of a typical Westphalian flora on the southern shores of the Thetys Sea. A few specimens recently collected by Mr. John Ball, of the Egyptian Survey, demonstrate the occurrence in the Sinai peninsula of species of *Lepidodendron* agreeing closely with *L. Veltheimi* Sternb. and *L. Rhodeanum* Sternb.[2]

In 1883 Prof. Zeiller[3] recorded eleven species of plants from the neighbourhood of Tete, in the Zambesi district (Map B, 9), identical with Stephanian species from the Coal Measures of Britain and the coal-basins of the Loire and other Continental areas. In discussing the bearing of the discovery Zeiller quoted some Carboniferous European species recorded by Grey from Cape Colony, but these are now generally admitted to have come from the Coal Measures of Europe. The occurrence of members of the northern Upper Carboniferous flora unaccompanied by any representatives of the *Glossopteris* flora has become increasingly difficult of interpretation, as the area occupied by the southern or *Glossopteris* flora has been extended by recent discoveries in German and Portuguese East Africa. The occurrence of northern species at Tete is in itself readily intelligible in view of the admixture of *Glossopteris* and European types in the Transvaal, but the collection received by Prof. Zeiller from M. Lapierre affords no evidence of such admixture. Dr. Gothan,[4] in a recent article, states that he found in a drawer in the Berlin "Museum für Naturkunde" several fossil plants from Tete collected by Dr. Wiese, among which he recognised several forms of *Glossopteris*, *e.g.* *G. indica* Schimp. and a type of frond very similar to *G. retifera* Feist. It would seem, therefore, that the Permo-Carboniferous vegetation in the Zambesi region was of the southern facies. Prof. Zeiller, in answer to an inquiry from Dr. Gothan, states that two engineers who were with the late M. Lapierre in Africa remember having seen the specimens collected and packed, and more recently in a letter to myself Prof. Zeiller expresses his opinion that there is no proof that the Tete fossils described by him in 1883, from lat. 16° 9′ S., were from the beds examined by Dr. Wiese in lat. $15\frac{1}{2}°$ S., long. 34° W. The alternative conclusions would seem to be that in the Zambesi district the northern and Gondwanaland floras coexisted, or that, as Dr. Gothan believes, there was some confusion between Tete specimens and fossils from a European coal-field. Without further evidence one is not justified in assuming the latter alternative to be correct, though it is exceedingly difficult to adopt the former conclusion in the face of discoveries made since the publication of Zeiller's paper.

The climate of the Coal age is often described as tropical, and this statement has found favour out of proportion to the soundness of the evidence on which it rests. It is, however, far from improbable that the physical conditions were such as to favour rapid growth; the absence of well-defined rings of growth in woody stems is, speaking generally, a striking characteristic of *Lepidodendron*, *Sigillaria*, *Cordaites*, and other arborescent plants, which points to the absence of seasonal changes. Arguments can be adduced from anatomical data supporting the view that several of the commoner plants grew in swampy soil or even with the bases of their stems submerged and in habitats to some extent physiologically dry, possibly in salt marshes or in peaty ground. A comparison between the forests of the Coal period and Recent peat moors has been made the foundation of a view that it was rather in a temperate than a tropical climate that the enormous mass of vegetable débris accumulated from which the coal seams were produced. In this connection it is pertinent to call attention to a recently described example of a tropical peat moor in Sumatra,[1] where some of the plants exhibit morphological features recalling those of certain Carboniferous genera. The accumulation of humus in the tropics may be considerable, and swamp-moors are by no means rare in the warmer regions of the world. The outstanding fact more particularly germane to our present thesis is the absence of any satisfactory evidence of the occurrence of glacial conditions on a large scale in the home of the northern flora.[2]

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[1] Zeiller (08).

[2] These plants at present in my possession have not yet been described; their comparison with the species named was suggested by Dr. Kidston.

[3] Zeiller (83).

[4] Gothan (12).

3.—THE SOUTHERN PROVINCE: THE *GLOSSOPTERIS* FLORA AND CLIMATIC CONDITIONS.

It has been urged by Dr. White,[3] in an interesting discussion of Permo-Carboniferous changes, that the term *Gangamopteris* flora is more appropriate than that of *Glossopteris* flora, on the ground that *Gangamopteris* does not transgress the limits of the Palaeozoic system, while *Glossopteris* persisted into the Mesozoic period. In view of the general use of *Glossopteris* as the name-plant of the southern flora, and as that genus undoubtedly reached its maximum development in the latter part of the Palaeozoic era, the reasons in support of the proposed change are hardly strong enough to outweigh established usage.

Briefly stated, the most striking characteristics of the southern flora are:—(i.) its association with deposits that bear unmistakable signs of the presence of glaciers or ice-sheets, and, in some cases, of the presence of floating ice; (ii.) the small number of species compared with the wealth of material obtained from the Permo-Carboniferous strata of the northern hemisphere; (iii.) the dominant part played by *Glossopteris* and *Gangamopteris*, genera unknown in the typical northern flora.[1]

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[1] Potonié (09).

[2] For discussions on the question of climate and references to literature, see Frech (97); Seward (04); Chamberlin and Salisbury (06); Koken (07); Eckardt (09); Carthaus (10); Haug (11).

[3] White, D. (07).

The approximate distribution of the true *Glossopteris* flora is shown by the areas shaded with parallel lines on Map B.

a. India, Afghanistan, and Persia.

In the Indian peninsula, the Talchir boulder beds, which are distributed over a wide area including places where the snow-line reaches its maximum height, rest unconformably on older rocks, and are succeeded by a series of sandstones and shales containing *Glossopteris*, *Gangamopteris*, *Cordaites* (formerly assigned to the genus *Noeggerathiopsis*), *Phyllotheca*, *Schizoneura*, and other genera. In 1875, Fedden[2] discovered the grooved and polished surface of an old Pre-Cambrian land-surface in the valley of the Penganga river, on which the Talchirs had been deposited. It is noteworthy that in India there are no plant-beds of Lower Carboniferous or Devonian age containing relics of a Pre-*Glossopteris* vegetation, such as existed in Australia and elsewhere in the southern hemisphere. Another fact of importance is the absence from the Indian flora of *Lepidodendron* and *Sigillaria*, members of a class represented in South Africa and South America by forms probably identical with northern species. A recent examination of some specimens described by Feistmantel as Coniferous stems[3] leads me to think that they may be fragments of a *Bothrodendron*; but the material is too imperfect to prove the existence of the Lycopodiales in Lower Gondwana rocks. Evidence as to the precise geological age, in terms of European chronology, of the plant-bearing strata is meagre, and it has been customary to designate the Talchirs and overlying beds Permo-Carboniferous. In the Salt range (lat. 32° 54′ N., long. 71°) the Talchirs are overlain by rocks containing Permian or Upper Carboniferous marine fossils, some of which are identical with Australian species. These marine beds, homotaxial with the freshwater strata of the peninsula, are regarded by Indian geologists as Upper Carboniferous. More recently additional data have been obtained from Kashmir, where Dr. Noetling discovered, in the Vihi valley, a few plants, *Gangamopteris kashmirensis* Sew., *Psygmophyllum*, etc., with some fish-remains and a Labyrinthodont compared by Dr. Smith Woodward with European Permian species.[4] Mr. Hayden,[5] who collected plants from the same region, considers that the *Gangamopteris* beds are not younger than Upper Carboniferous. A further account of the geology of Kashmir is given by

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[1] For a general account of the *Glossopteris* flora and for references, see Zeiller (97); Arber (05); and Seward (04). For a critical summary of our knowledge of the glacial beds, see Penck (00); Bertrand (09).

[2] Fedden (75); see also Medlicott and Blanford (93), p. 158.

[3] Feistmantel (81), pl. XLVII A, figs. 5–7.

[4] Seward and Woodward (05); Seward (07^2).

[5] Hayden (07), p. 38.

Mr. Middlemiss,[1] who found *Gangamopteris* below the Zewan series which contains *Athyris*, *Productus*, and other marine shells.

Dr. Griesbach[2] demonstrated the extension of the Talchir boulder beds into Afghanistan (Herat, Map B, 1), and Persia (Khorassan), and he discovered a few fragments of Lower Gondwana plants; but our knowledge of these regions is very incomplete.

b. Australia and Tasmania.

Since the discovery by Dr. Selwyn, in 1859, of boulder beds in the valley of the Inman river in South Australia, evidence has been steadily increasing in support both of the glacial origin and wide distribution of deposits homotaxial with and lithologically in agreement with the Talchirs of India, the Dwyka of South Africa, and the Orleans conglomerate of South America. Glaciated rock-pavements have been discovered at Adelaide and elsewhere.[3] As Prof. Edgeworth David[4] has shown in his paper on "Evidence of Glacial Action in Australia in Permo-Carboniferous Times," there can be no doubt that a vast area of Australia, including Tasmania, is occupied by glacial deposits and overlying plant-beds homotaxial with the Lower Gondwana series of India. There is conclusive evidence of the existence both of land and floating ice. Plants of the *Glossopteris* flora have been obtained from the Mersey coal-field of Tasmania, the Newcastle and Muree series of New South Wales, the Bacchus Marsh sandstone of Victoria, the Bowen river series of Queensland, from Yellow cliff in the interior of the continent, from the Collie river coal-field, the Gascoyne river and other localities in Western Australia, and recently from the Mount Mulligan coal-field in the York peninsula in the extreme north.[5] The occurrence of *Sphenophyllum speciosum* (Feist.) in this north Australian coal-field extends the range of the genus in the southern province. *Sphenophyllum*, a common northern type, has hitherto been recorded in association with *Glossopteris* only in India and in Natal.

Important evidence as to the age of the lower *Glossopteris*-beds is supplied by the occurrence of marine beds above and below the coal-seams of the Muree series containing Carboniferous shells.

Lower Carboniferous and Devonian plants are recorded from New South Wales, Victoria, and Queensland, from rocks below the glacial tillite, testifying to the existence in these regions, as in many other parts of the world, of a cosmopolitan Pre-*Glossopteris* flora. In the greater purity of the *Glossopteris* flora, in the sense that no species of *Lepidodendron* or *Sigillaria* have been found above the glacial beds, Australia agrees with India.

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[1] Middlemiss (09).

[2] Griesbach (85); (86); (87).

[3] Penck (00); Howchin (12). Both authors give references to other sources.

[4] David (96). See also David (87).

[5] Ball (12).

c. SOUTH AMERICA.

In Brazil Pre-Carboniferous strata containing marine fossils are succeeded unconformably by sandstones and shales resting on granite and passing up into the Orleans conglomerate, a rock consisting of boulders embedded in an unstratified argillaceous material, and closely resembling the Talchir beds of India. The recent account of this conglomerate by Mr. White[1] would seem to confirm the earlier opinion of Derby, that in South America there is evidence of widespread glacial phenomena. The occurrence of *Rhacopteris*, a *Lepidodendron* similar to *L. nothum* Ung., and other plants in the province of San Juan in Argentina[2] and elsewhere, establishes the close resemblance between the Pre-*Glossopteris* flora of South America and that in other parts of the world. Above the Orleans conglomerate in Brazil, and from beds in the same position in the Argentine, several members of the *Glossopteris* flora have been recorded, including *Glossopteris*, *Gangamopteris*, *Neuropteridium*, *Cordaites*, *Phyllotheca*, and other genera. In 1895 Zeiller[3] described *Lepidophloios laricinus* Sternb., a northern type, in association with several members of the *Glossopteris* flora in Brazil, together with *Lepidodendron* and *Sigillaria*, an admixture similar to that in the plant-beds at Vereeniging in the Transvaal. From the Argentine Kurtz[4] has recorded several Gondwana plants, and Bodenbender[5] records *Lepidodendron* and *Lepidophloios*. More recently Dr. White[6] has described several species from Brazil, for the most part widely distributed southern types, but including *Sigillaria* and a few other northern plants. A problematical fossil named by White *Hastimima*, and doubtfully referred to the plant-kingdom, has since been shown to be founded on fragments of a Eurypterid very similar to a Devonian species from Ireland.[7] This genus was found in the lower plant-bearing strata in the S. Catharina system. The species *Psaronius brasiliensis* Ung. is the only representative in the *Glossopteris* flora of this genus of tree-ferns characteristic of the northern province: another type of fern stem has recently been described by Graf zu Solms-Laubach[8] as *Tietea singularis*. The occurrence of these ferns with *Lepidophloios*, *Sigillaria* and *Cordaites* in beds above those containing the oldest examples of the *Glossopteris* flora may, as Dr. White suggests, indicate a change from the more rigorous conditions represented by the Orleans conglomerate.

d. FALKLAND ISLANDS.

Professor Nathorst's identification of some imperfectly-preserved specimens of *Phyllotheca*-stems first suggested the occurrence of the *Glossopteris* flora in the Falkland Islands (Map B, O). Six years later Dr. Halle published an important memoir, "On the Geological Structure and History of the Falkland Islands,"[9] in which he gives the results of his own investigations and those of other members of the Swedish South Polar Expedition (1901–03). He records the occurrence of a few Devonian plants, *e.g.* Lepidodendroid fragments recalling *Lepidodendron nothum* Ung., and *L. australe* McCoy, indicating the existence in this region of the widely spread Pre-*Glossopteris* flora. From Permo-Carboniferous strata assigned to the Lafonian series (so named from Lafonia, the southern peninsula of the eastern island), he records *Glossopteris indica*, *G. Browniana*, and other forms, also *Gangamopteris cyclopteroides*, species of *Phyllotheca*, a *Dadoxylon*, and a few other plants. Associated with the plant-beds are pebble-bearing deposits with the characters of tillite, as defined by Prof. Penck, containing striated boulders and facetted pebbles. The discovery of this typical Lower Gondwana flora and of glacial deposits, demonstrates the southern extension of Gondwanaland beyond the confines of the present mainland.

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[1] White, I. C. (08).

[2] Szajnocha (91).

[3] Zeiller (95).

[4] Kurtz (94); see also Zeiller (96).

[5] Bodenbender (02).

[6] White, D. (08).

[7] Seward (09); Woodward, H. (09).

[8] Solms-Laubach (13).

[9] Nathorst (06); Halle (12).

e. SOUTH AFRICA AND MADAGASCAR.

The presence of Permo-Carboniferous boulder beds in South Africa was first recognised by Sutherland in 1870 in Natal, and in recent years much fresh evidence has been gathered in support of his interpretation of the nature of these widely spread glacial deposits, known as the Dwyka conglomerate, which form the base of the Karroo formation and in several places rest on smoothed and deeply furrowed platforms of older rocks.[1] Immediately above the Dwyka is a thick series of freshwater beds containing *Glossopteris*, *Gangamopteris*, and several other genera with seams of coal and occasionally an old land-surface with the spreading roots of trees.[2] These lower plant-beds belong to the Ecca series and are clearly homotaxial with the Lower Gondwanas of India. Above them are the Beaufort beds containing many reptiles resembling European species.[3] The *Glossopteris* flora has left abundant traces in Cape Colony, the Transvaal, the Orange River Colony, Zululand,[4] Rhodesia,[5] Portuguese East Africa,[6] and as far north as Lake Nyasa.[7] A notable feature of the South African flora is the association with *Glossopteris* and other southern genera of a northern species of *Sigillaria* near Johannesburg,[8] while at Vereeniging, on the Vaal river, Mr. Leslie discovered *Sigillaria*, *Lepidodendron*, and *Bothrodendron* indistinguishable from northern species.[9] Dr. Arber records the occurrence in Rhodesia of *Glossopteris* associated with fragments resembling *Sigillaria*. As already stated, there is evidence of the existence of a Devonian flora in South Africa.

In 1908 M. Boule announced the discovery of fossil reptiles in Madagascar agreeing with some European species and apparently allied to the South African genus *Saurosternon*. By a fortunate accident a leaf-impression was associated with one of the skeletons, and this was identified by Prof. Zeiller[1] as *Glossopteris indica* Schimp., an identification which demonstrates the former occurrence of the *Glossopteris* flora on the eastern side of the Mozambique channel.

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[1] Davis (06); Lomas (06); Rogers and du Toit (09); Mellor (05).

[2] Mellor and Leslie (06).

[3] For a general account, see Rogers and du Toit (09).

[4] Seward (07); Etheridge (01).

[5] Arber (03). Since this summary was written a paper has been published in Engler's "Botanische Jahrbücher" recording the occurrence of *Glossopteris* in German East Africa (7.15° S. Lat., 37.9° E. Long.) [Brehmer (14)].

[6] Potonié (00). [7] Arber (10). [8] Seward (97). [9] Seward and Leslie (08).

f. MALAYA.

In 1885 Mr. Tenison-Woods[2] stated that he had identified *Phyllotheca australis* Brongn. and *Vertebraria* from the Sarawak coal-bearing strata in Borneo (Map B, L), but so far as I know this preliminary announcement has not been followed by an illustrated description of the fossils, and until more satisfactory evidence is adduced the occurrence of the *Glossopteris* flora in Borneo cannot be regarded as established.

From a locality between Penang and Kuala Lumpur (Map B, K) Mr. Scrivenor[3] records the occurrence of deposits resembling till and boulder clay, which he regards as homotaxial with the Talchir beds of India. No plants have been found. While admitting the probability that Malaya may have been in part included in the Gondwanaland area, the evidence at present available is not conclusive.

4.—THE OCCURRENCE OF *GLOSSOPTERIS* AND OTHER SOUTHERN TYPES IN UPPER PALAEOZOIC FLORAS IN RUSSIA AND SIBERIA.

The discovery by Prof. Amalitzky[4] of *Glossopteris indica* and two other species of the genus with *Gangamopteris cyclopteroides* in Upper Permian rocks on the River Dwina (Map B, A), in association with reptilian remains agreeing with South African Lower Karroo species, demonstrated an unexpected extension of the flora and fauna of Gondwanaland into European territory. With *Glossopteris* and *Gangamopteris* were found *Callipteris*, *Taeniopteris*, and other plants identical with European types. The close resemblance between some Lamellibranchs discovered in 1892 in this part of North Russia and species from South Africa, suggested a stratigraphical correlation between the northern and southern strata, and this received confirmation through the subsequent discovery of *Glossopteris* and *Gangamopteris*. Several years before Amalitzky's sensational discovery, Schmalhausen[5] had described a collection of plants from Petschora (Map B, B) and the Lower Tunguska river (Map B, E), also from the Altai Mountains (Map B, H), which he regarded as indicative of a Jurassic age. The Altai plants had been assigned by previous writers to the Palaeozoic system. A revision of Schmalhausen's determinations by Zeiller[6] led him to class the floras as Permian: he recognised among Schmalhausen's supposed Jurassic ferns several well-known Upper Carboniferous and Permian European types, and one of the Russian species he compared with a North American Permian species. Schmalhausen's *Phyllotheca deliquescens* is compared with *P. indica*, and the leaves named *Rhiptozamites Goepperti* Zeiller regards as identical with the Lower Gondwana *Noeggerathiopsis Hislopi*. It is, however, important to bear in mind that *Phyllotheca* is not exclusively a southern genus; species are known from Jurassic rocks of Italy, and a species, *P. Rallii*, has been described by Zeiller[1] from the Coal Measures of Heraclea in Asia Minor. In a later contribution Zeiller[2] described additional specimens from the Kusnetz basin (Map B, H), and extended his revision of Schmalhausen's species. The specimens described as *Cyclopitys Nordenskioldi* Schmal. he believes to be probably identical with *Annularia stellata*, a Stephanian and Permian European species, and closely allied to *Annularia australis*. Schmalhausen's *Zamiopteris glossopteroides* is compared with the Stephanian and Permian genus *Lesleya*.[3] These floras—Tunguska, Kusnetz, Altai, and Petschora—are clearly Permian in age, and while in the main agreeing with other European and to some extent with North American Permian floras, they include a few types identical with or closely allied to members of the *Glossopteris* flora. More recently Gothan[4] has discussed the affinities of the Tunguska and other Siberian plants, and his conclusions are in general agreement with those of Zeiller.

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[1] Boulé (08).
[2] Tenison-Woods (85).
[3] Scrivenor (12).
[4] Amalitzky (97); (01); Zeiller (98).
[5] Schmalhausen (79); (83).
[6] Zeiller (96^2).

One of the most widely distributed species represented in the Siberian Permian floras is that described by Goeppert as *Cordaites aequalis*; it is recorded from the Petschora basin,[5] Orenburg[6] (Map B, C), from the Lower Tunguska, the Khatanga river (Map B, D), the Angara river (Map B, F), Sudzenka[7] (province Tomsk; Map B, G), North-West Mongolia, and elsewhere in Siberia, in addition to the numerous localities in India and the southern hemisphere. It was suggested by Kosmovsky that Goeppert's *Cordaites aequalis* from the Altai Mountains is identical with Bunbury's species *Noeggerathiopsis Hislopi* from the Lower Gondwana of India, and this opinion has recently been confirmed by Zalessky.[8] *Noeggerathiopsis* has long been recognised as in all probability a member of the Cordaitales, and a few years ago I ventured to substitute *Cordaites* for *Noeggerathiopsis* as the more appropriate name.[9] Additional evidence, which need not be discussed here, has been brought forward by Zalessky and others which leaves no room for doubt that the genus *Cordaites* flourished over a wide area in both hemispheres in Permo-Carboniferous times. Dr. Scott's and Mr. Maslen's recent researches have demonstrated the existence in Carboniferous rocks of Cordaitalean stems, assigned by them to a new genus *Mesoxylon*,[10] which can be distinguished from those of *Cordaites* only by certain anatomical characters. In the absence of well-preserved specimens the two genera cannot be distinguished; and we have no means of knowing whether the leaves described as species of *Cordaites* were borne on stems of the *Cordaites* or *Mesoxylon* type. The name *Cordaites* is therefore used in a wide sense, and includes specimens that, were their structure preserved, would be assigned to *Mesoxylon*. As Zeiller pointed out, Schmalhausen's *Rhiptozamites Goepperti* is undoubtedly the same plant as *Noeggerathiopsis*, and therefore presumably as *Cordaites aequalis*.

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[1] Zeiller (99), p. 65.

[2] Zeiller (02^2).

[3] Seward (10), p. 517.

[4] Gothan (11).

[5] Zalessky (13).

[6] Schmalhausen (87).

[7] Zalessky (12).

[8] Zalessky (12^2).

[9] Seward and Leslie (08), p. 121.

[10] Scott and Maslen (10); Maslen (11); Scott (12).

In recent years there have been several important additions to our knowledge of Permian Siberian floras by Zalessky and other Russian writers, but a full discussion of these would extend our survey beyond reasonable length. The main point is that further evidence has been collected pointing to an association of northern and southern plants over an area extending from N.W. Mongolia through Siberia to north Russia. Zalessky[1] has described several specimens from the River Adzva in the Petschora basin, which he assigns to an Upper Permian horizon, including *Gangamopteris rossica*, a species founded on leaves agreeing in shape and in the absence of a definite midrib with other forms of the genus, but distinguished by the rarity of anastomoses between the secondary veins, a feature regarded as due in part to imperfect preservation. This species may be identical with that described by Schmalhausen as *Zamiopteris glossopteroides*, which Zeiller compares with *Lesleya*. It is, however, interesting and suggestive that a few cross-connections occur between the veins, and it is by no means unlikely that Zalessky is correct in adopting the generic name *Gangamopteris*. The almost complete absence of anastomoses in some *Glossopteris*-fronds from India and South Africa affords a parallel case. Among other plants from the Adzva river are *Schizoneura gondwanensis*, *Danaeopsis Hughesi*, an Indian and South African species recorded also by Krasser[2] from China, and by Zeiller[3] from the Rhaetic of Tonkin, *Cordaites aequalis*, species of *Dadoxylon*, and some coarsely veined leaves, probably Cordaitalean, referred to a new genus *Phylladoderma*. As Zalessky points out, we have in this flora another indication of an admixture of northern and southern types. The species named by Zalessky *Callipteris uralensis*, originally described in 1840 as a species of *Neuropteris*, is founded on fronds similar in habit to *Neuropteridium validum*, an Indian and southern hemisphere plant.

Since Javorovskij's account of the plant-beds of Sudzenka, in the province of Tomsk, additional specimens have been described by Petunnikow[4] and Zalessky,[5] which indicate a further association of European species with plants agreeing with members of the *Glossopteris* flora; the portions of fronds named by Petunnikow *Neuropteridium sibiricum* are hardly distinguishable, except by their smaller size, from *Neuropteridium validum*. The genus *Neuropteridium*, though characteristic of the older Gondwana floras, is not confined to the southern province. A species, *N. grandifolium*, from the Bunter sandstone of the Vosges, is very similar to the Indian species, and it is highly probable that there is not a real generic difference between *Neuropteridium* and some Permian European types referred to *Callipteris* and other genera. The specimens figured by Zalessky from Sudzenka as *Gangamopteris cardiopteroides*, previously named by Schmalhausen *Neuropteris*, and by Petunnikow referred to *Cardiopteris*, are assigned to *Gangamopteris* on the ground of the occurrence of a few faint oblique cross-connections between the curving secondary veins in the large and broad pinnules. The photographs[1] do not carry conviction as to the presence of true anastomosing veins, and the fact that the Sudzenka and Mongolian specimens are portions of compound fronds is a serious obstacle in the way of adopting the generic name *Gangamopteris*. While agreeing with Zalessky in his reference of the Petschora leaves to *Gangamopteris*, I cannot accept his use of that designation for the Sudzenka and Mongolian specimens.

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[1] Zalessky (13).

[2] Krasser (00), p. 145.

[3] Zeiller (03), p. 57.

[4] Petunnikow (09).

[5] Zalessky (12).

Enough has been said to show that in Permian times there was a closer resemblance between European and Asiatic floras in the northern hemisphere and the vegetation of Gondwanaland than has generally been supposed. It is probable that, as Zalessky says, in the latter part of the Palaeozoic era there was a connection between the opposite shores of Suess's Thetys sea either by an isthmus or through a chain of islands.

5.—THE OCCURRENCE OF *GLOSSOPTERIS* IN LOWER MESOZOIC FLORAS.

a. Tonkin.

In an important memoir on a large collection of plants from the mines of Hongay and the island of Kebao in Tonkin (Map B, J), Zeiller[2] describes specimens of *Glossopteris indica* and *Noeggerathiopsis Hislopi* (=*Cordaites aequalis?*), associated with numerous species of ferns, cycads and other plants in many cases specifically identical with Rhaetic types from other parts of the world. Among species of special interest in connection with the distribution of types represented in the *Glossopteris* flora is one described by Zeiller as *Danaeopsis* (*cf. D. Hughesi* Feist.). This plant occurs in India in passage-beds between the Lower and Upper Gondwana series, in Rhaetic beds in South Africa, in the Upper Permian of the Petschora basin, and in China. A specimen described by Shirley as *Neuropteris punctata* from the Ipswich beds of Queensland should, perhaps, be referred to *Danaeopsis*. The discovery of *Glossopteris* in the Rhaetic of Tonkin, where one species occurs, and in the Rhaetic flora of a neighbouring Chinese province, where it is represented by *Glossopteris angustifolia*, demonstrates the persistence of the genus into the Mesozoic era in the southern region, while further north it has not been found in rocks higher than the Permian.

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[1] Zalessky (12), figs. 4, 7, 14.

[2] Zeiller (03).

b. Mexico.

In a preliminary account of his investigations in Mexico (Map B, N), Dr. Wieland[1] records the discovery of *Glossopteris* with *Noeggerathiopsis Hislopi* (= *Cordaites*) in the lower strata of a thick plant-bearing series accompanied by several ferns and cycadean species indicating a geological age at least as recent as the Triassic period. As Zeiller has shown, *Glossopteris* persisted into the Upper Triassic or Rhaetic period in Tonkin, and it is now generally admitted that lineal descendants of *Cordaites* flourished in Europe at least as late as the Triassic period.

6.—THE QUESTION OF THE OCCURRENCE OF *GLOSSOPTERIS* IN NEW ZEALAND.

Some specimens collected by Mr. McKay in the Canterbury Alps were identified by Hector[2] in 1878 as *Glossopteris*-leaves, but his identification was contested. A very welcome contribution to our meagre knowledge of the ancient floras of New Zealand has recently been published by Dr. Arber,[3] who describes a collection made by Mr. Lillie, a member of Capt. Scott's last expedition, and Mr. Speight from the Mount Potts beds in Ashburton county, Canterbury. The most interesting specimens are impressions of leaves, identical in form with those of some types of *Glossopteris*, which Arber refers to a new genus *Linguifolium*. The genus is instituted on the ground that the forked secondary veins are not connected by anastomoses, though in a few places there appear to be some cross-connections which are considered to be due to the displacement of a film of carbon and are not regarded as true connecting veins. Through the courtesy of Mr. Lillie I was able to examine the fossils: while admitting the almost complete absence of anastomoses, I believe that in one or two cases there are actual cross-connections and that the fronds are very closely related to such species as *Glossopteris indica* and *G. Browniana*. Dr. Arber speaks of *Linguifolium Lillieanum* as a homoeomorph of *Glossopteris*, a term first applied to Brachiopods and Ammonites to indicate a close resemblance between species "of distinct origin and descent."[4] Zeiller[5] has drawn attention to the occurrence of leaves of *Glossopteris indica* in the Karharbari beds of India in which there are a few connecting veins, and an interesting example of departure from the normal type is afforded by a leaf described from the Vaal river in South Africa in which there are practically no anastomoses. This form, *Glossopteris angustifolia* var. *taeniopteroides* Sew. and Les.,[6] is associated with typical *Glossopteris*-leaves and in shape agrees absolutely with narrow *Glossopteris*-fronds. Mr. Lillie's collection includes casts of Equisetaceous stems compared by Arber with *Phyllotheca* and *Schizoneura* which appear to be indistinguishable from specimens of *Schizoneura* described by Zeiller from Tonkin.

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[1] Wieland (13). [2] Hector (78). [3] Arber (13); Marshall (12), p. 182. [4] Arber (03^2).
[5] Zeiller (02), Pl. III.; *cf.* also Zeiller (03), Pl. XVI, fig. 2.
[6] Seward and Leslie (08), p. 113.

The Mount Potts flora as a whole is, as Dr. Arber says, no doubt Upper Triassic or Rhaetic; but I venture to think that the further conclusion that there is "no evidence that New Zealand ever formed part of Gondwanaland" is open to question. The leaves on which the genus *Linguifolium* is founded are, I believe, if not generically identical with, at least very closely related to *Glossopteris*. There is, moreover, a close resemblance between several New Zealand species and plants from the Rhaetic floras of Tonkin, South Africa, and elsewhere which contain representatives of *Glossopteris* or other members of the later floras of the Gondwana continent.

7.—CLIMATIC CONDITIONS IN THE SOUTHERN BOTANICAL PROVINCE.

The almost constant association of Permo-Carboniferous plant-beds in India and the southern hemisphere with glacial deposits is a fact of outstanding importance in relation to questions concerning the climatic conditions under which the *Glossopteris* flora flourished. The fact that almost all the records of the *Glossopteris* flora are preserved as casts or impressions and not as petrifactions deprives us of a most important clue as to the kind of habitat in which the plants grew. Petrified stems from Lower Gondwana rocks in India, South Africa, and in some cases from South America, possess clearly marked rings of growth in contrast to the more uniform diameter of the tracheids composing the wood of trees from the northern province. Some wood of Lower Gondwana age recently sent to me by the Director of the Indian Geological Survey, an account of which is shortly to be published by Miss Holden, affords a remarkable example of sharply differentiated spring and summer wood: a similar differentiation is seen in a *Dadoxylon*-stem received from Mr. Leslie from Vereeniging, and Permo-Carboniferous woods from Australia[1] exhibit equally clear rings of growth. It is interesting to find that in wood from a higher horizon in the *Glossopteris*-beds of Brazil, probably those from which the *Psaronius* was obtained, there are no distinct rings, a fact interpreted by White as evidence of ameliorated conditions. The enormous abundance of detached leaves of *Glossopteris* in many places may indicate a gregarious and deciduous plant that grew with few associates over wide stretches of ground. *Cordaites*, though represented by a few species in the southern flora, reached its maximum development in the northern province, but the occurrence of the same genus of Recent plants in very different climatic environments warns us against the assumption that the presence of this genus in Gondwanaland implies conditions similar to those in the north. From the analogy of the habitats of Recent tree-ferns and of members of the Marattiaceae, the family to which *Psaronius* is most nearly allied, the occurrence of *Psaronius brasiliensis* in South America might be regarded as an argument in favour of a sub-tropical or tropical climate. On the other hand, the existence of tree-ferns in close proximity to the Tasman Glacier in New Zealand demonstrates the adaptability of plants to a wide range of climate. The small number of genera and species in the *Glossopteris* flora, in contrast to the much larger number in the European Coal Measures, and the absence of several types characteristic of the Coal period swamps, suggest differences both in climate and in geographical conditions. The paucity of a flora in genera or species is, however, hardly a safe index of climate. As Brockmann-Jerosch[1] has recently pointed out, the determining factor with regard to the richness of a flora in species may be physiographical or physical and not climatic.

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[1] Arber (05), p. 191.

The presence of the large stems discovered by Commander Campbell and Mr. Priestley, even granting the possibility of transport from a locality further from the Pole, clearly points to an Antarctic climate very different from that under which the mosses and lichens exist at the present day. There is nothing inconsistent with our knowledge of the relations of Recent plants to temperature in the association of vigorous trees and a dense growth of smaller plants on the slopes of mountains with ice-filled valleys. There is a further question to be considered, namely, the contrast between the vegetation preserved in Pre-Gondwana strata and that from beds in close relation with glacial deposits. The conclusion seems inevitable that the Lower Carboniferous and Devonian floras flourished under fairly uniform conditions. Towards the close of the Carboniferous era the conditions changed: in the southern hemisphere and in India the configuration of the land favoured the accumulation of snow from year to year and the production of glaciers and icebergs, while in the northern province there were extensive swamps and ice-free hills with their respective plant-associations differing in many respects from the vegetation of the southern continent, though sharing a few genera in common. The association in South America and South Africa of a few northern plants with the *Glossopteris* flora may be due to the southern migration of some of the more hardy representatives of the warmer region north of the equator; or it may point to the survival in these districts of genera which belonged to the Pre-*Glossopteris* flora.

8.—ANTARCTICA AND GONDWANALAND.

Among the questions raised by the distribution of the glacial beds and the *Glossopteris* flora, is the possibility of a shifting of the earth's axis in the course of past ages. A map given by Dr. Koken[2] shows a hypothetical grouping of land and water with the South Pole in the middle of the present Indian Ocean. It has, however, been pointed out by Penck and other writers that the striae observed on rock-platforms in different parts of Gondwanaland do not coincide with a radial movement of ice either from the present Pole or from a centre occupying the site indicated in Koken's map. Another difficulty is the absence of any widely spread traces of glacial action in

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[1] Brockmann-Jerosch (14).

[2] Koken (07).

Permo-Carboniferous times in the North American continent in the neighbourhood of North West Mexico, where the North Pole would be situated on the assumption that the suggested shifting of the earth's axis is a tenable hypothesis. But these are problems beyond the scope of this article; our chief concern is with the polar extension of Gondwanaland that is indicated by the recent discovery of *Glossopteris* in latitude 85° S.

If we assume that the axis of the earth has remained approximately fixed at least since the Palaeozoic era, the occurrence of plants such as those discovered on the Priestley Glacier raises the question of the effect of the long polar night on vegetation. We know that arborescent plants such as Willows and Junipers are able to exist under an Arctic climate, but their growth is seriously affected not merely by the low temperature, but by the desiccating effects of the wind, and it is the latter that in some regions determines the tree-limit. Kihlman[1] describes a Juniper with a diminutive stem 83mm. thick, showing at its base 544 rings of growth, the average breadth being 0·19mm. The stems, discovered in latitude 75° S., could clearly not have grown under conditions comparable with those which now characterise the Antarctic continent. The dwarfed and creeping habit of Arctic trees is, however, not attributable to the absence of sunlight over an extended period, but to other inhibiting causes. The concentrated activity of the plant-machine in Greenland and other Arctic countries compensates for the short duration of the growing period, and the substitution of a continuous period of darkness for the daily recurring hours of darkness is not a serious obstacle to the existence of perennial plants. A difficulty that besets the path of the plant physiologist is to discriminate between the various factors controlling plant-life, and if we would measure the influence of a long polar night, it is necessary to eliminate the effects produced by the lowering of temperature and other factors. It may be assumed that in the days when *Glossopteris* and other genera flourished on Antarctica the climatic conditions, at least as regards temperature, were more favourable than now, but we lack experimental data to give us a clue to the nature and extent of the influence of a prolonged sunless period. There is no serious difficulty in the way of Arctic or Antarctic plants surviving the winter months either in a condition similar to that of deciduous trees in a European winter, or even as evergreens living at low pressure on the surplus food manufactured in the course of the prolonged period of sunshine.

That there has been a considerable change of climate is certain, but the palaeobotanical data cannot be regarded as evidence favourable to an alteration in the position of the earth's axis.

Recent traverses through South Victoria Land have added considerably to our knowledge of a portion of the Antarctic land, but for the most part the floating termination of the land-ice[2] beyond which explorers have penetrated for short distances at different points, forms the edge of a *terra incognita* (Map C). The available geographical data afford clear indications of the existence of a great Antarctic continent at least as large as Europe; for this continent Suess[1] has proposed the name Antarctis, and Nordenskjöld[2] in his excellent summary of facts concerning both the regions that lie beyond the edge of the land-ice and the subantarctic islands, speaks of the polar continent as Antarctika. The sedimentary strata included under the comprehensive term Beacon Sandstone series are at least in part of Palaeozoic age; the fish-remains from Mt. Suess (Map A, 77° S. lat.) point to a Devonian horizon, while the beds containing the fragmentary leaves of *Glossopteris*, viewed in the light of the geological range of the genus in other parts of the world, may be as old as Upper Carboniferous or as late as the Rhaetic period. It is, however, by no means impossible that *Glossopteris* and other genera flourished on this Antarctic continent (Map B, R) at a period anterior to that which witnessed their dispersal beyond the Antarctic circle.

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[1] Quoted by Schimper (03), p. 676.

[2] *See* Map C, "Edge of unexplored area."

In a letter to Hooker, Darwin wrote: "Nothing is more extraordinary in the history of the Vegetable Kingdom, as it seems to me, than the *apparently* very sudden or abrupt development of the higher plants. I have sometimes speculated whether there did not exist somewhere during long ages an extremely isolated continent, perhaps near the South Pole."[3] The origin of the higher plants is still an unsolved problem, but knowledge acquired since 1881, the date of Darwin's letter, renders it difficult to escape from the conclusion that the ancient continent of Gondwana extended to within a short distance of the South Pole or even to the Pole itself, whether as a continuous continent or as an archipelago of islands cannot be determined. Meagre as it is, the material collected by the Polar Party calls up a picture of an Antarctic land on which it is reasonable to believe were evolved the elements of a new flora that spread in diverging lines over a Palaeozoic continent, the *disjuncta membra* of which have long been added to other land-masses where are preserved both the relics of the southern flora and of that which had its birth in the north.

Dr. W. T. Blanford,[4] who was one of the first to grasp the importance of the questions raised by the geographical distribution of the *Glossopteris* flora, expressed the view that an Antarctic continent was the original area of development of many plants. The same opinion has been offered by subsequent writers, and in 1897 I wrote: "There is not wanting evidence in favour of the *Glossopteris* flora having been first differentiated in an Antarctic continent towards the close of the Carboniferous epoch."[5] The discovery of *Glossopteris* on the Buckley Island moraine supplies what is needed to bring hypothesis within the range of established fact.

In his sketch-map of the Antarctic regions, Nordenskjöld[6] shows the position of a

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[1] Suess (08).

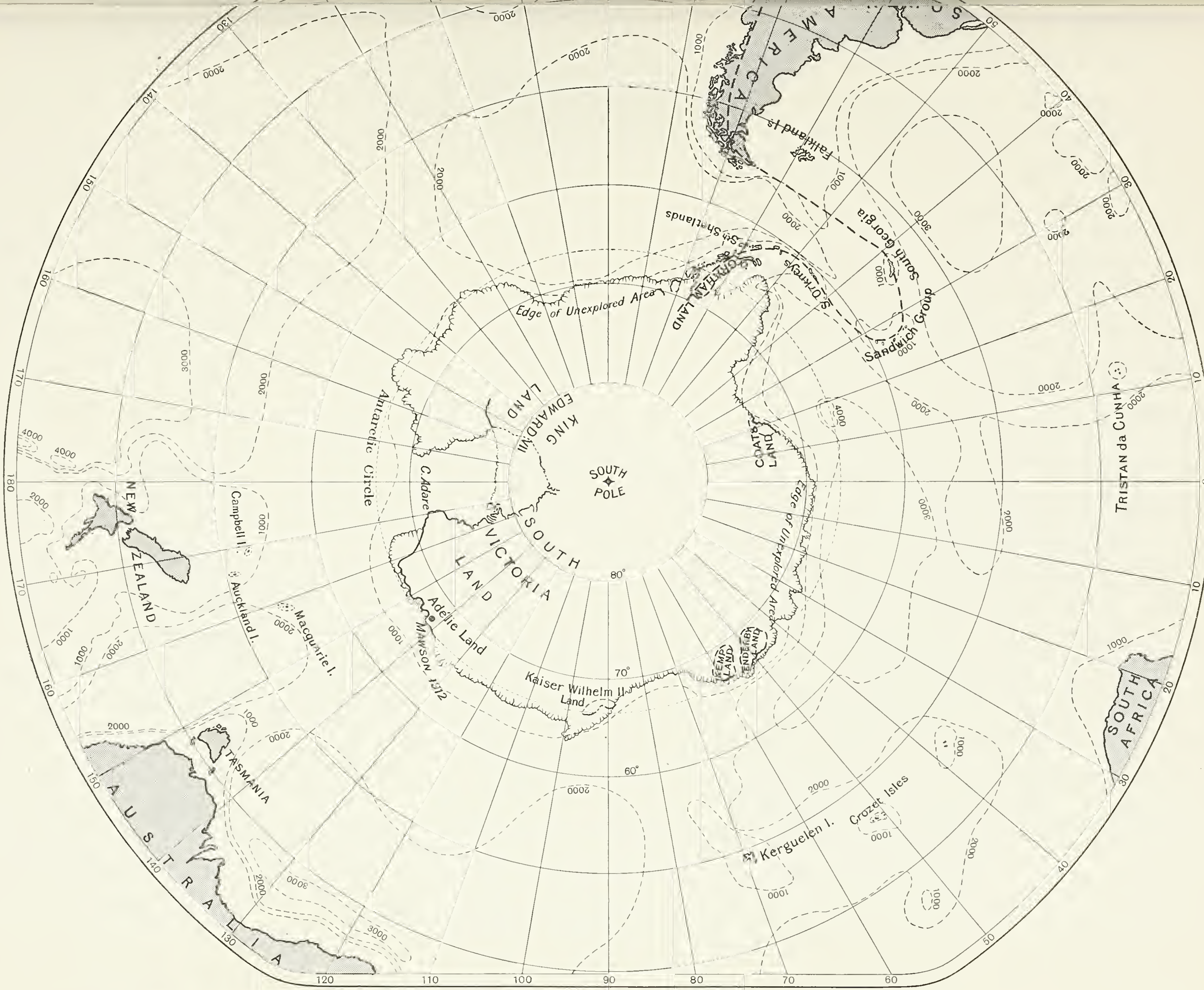
[2] Nordenskjöld (13).

[3] Life and Letters of Charles Darwin, Vol. III, p. 248, *London*, 1887.

[4] Blanford (84); see also Zeiller (97).

[5] Seward (97), p. 336.

[6] Nordenskjöld (13).



MAP C.—The Antarctic Regions, being a simplified form of the map published by Messrs. Stanford. The dotted line connecting South America with Graham Land is taken from a map published by Dr. Nordenskjöld in 1913.

possible connecting bridge between Antarctica and South America. This is indicated by the broken line on Map C, extending from the Southern Andes through South Georgia Island, and then sweeping back through the South Orkney islands and the South Shetland group to Graham Land. The position of the contour-line of shallower soundings (see Map C) accords with this view.

It must be left to others to deal more fully and with first-hand knowledge with the geological problems suggested by the discovery of *Glossopteris* in South Victoria Land. Mr. Griffith Taylor[1] has called attention to resemblances between the eastern side of Australia and Victoria Land, and in the structure of South Africa there are points of contact with the polar area. It is by a comparative study, in the light of recently acquired data, of the southern extremities of South America, South Africa, and Australia, and what remains of the continent within the Antarctic circle, that progress may be expected towards a better understanding of the geographical and geological problems of Antarctica.

The heroic efforts of the Polar Party were not in vain. They have laid a solid foundation ; their success raises hope for the future, and will stimulate their successors to provide material for the superstructure.

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[1] Scott's Last Expedition, Vol. II, p. 417.

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—— (93) *See* Medlicott and Blanford.

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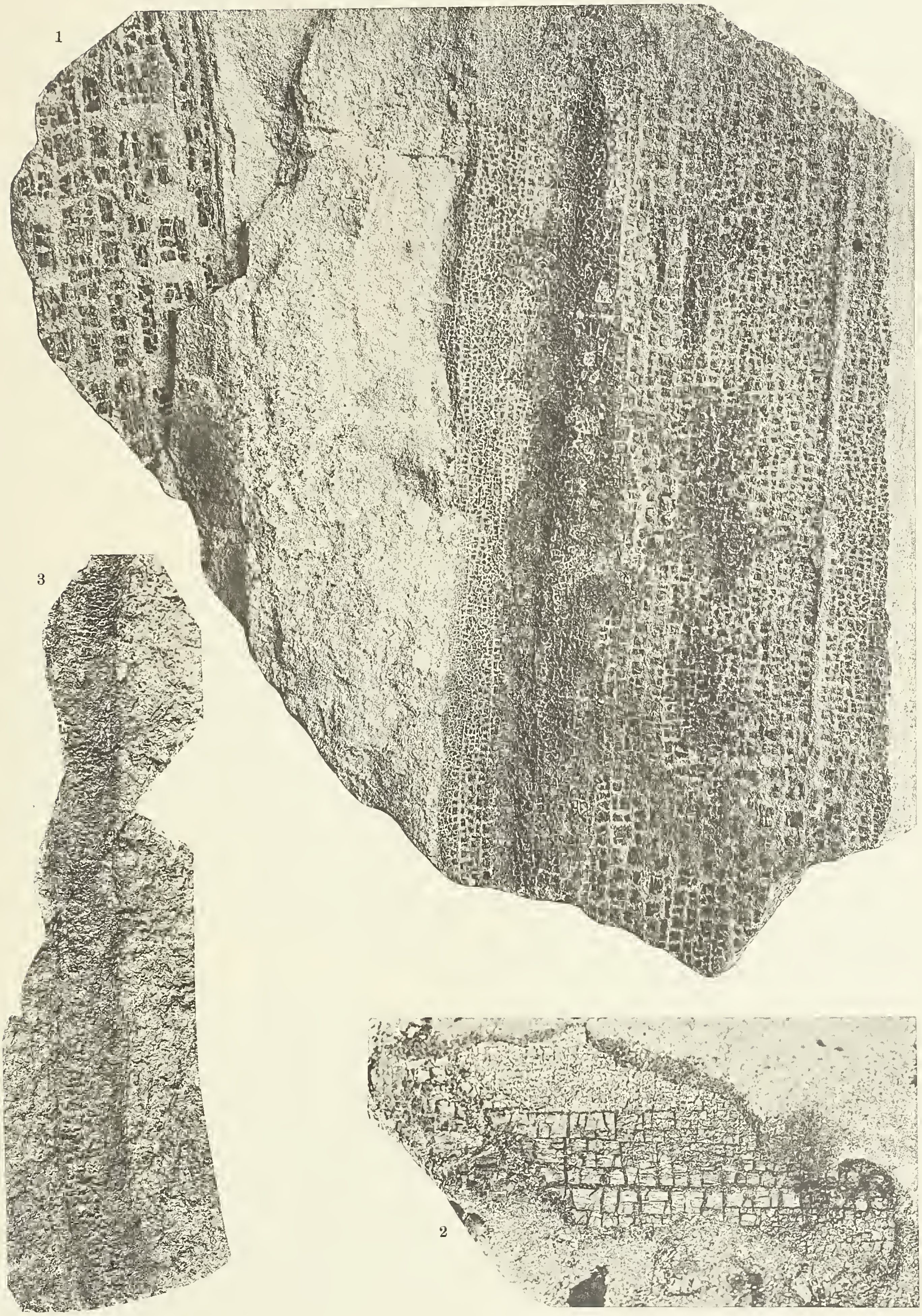
PLATE I.

FIG. 1.—Carbonised pieces of stem from the Priestley Glacier. Specimen A. $\frac{1}{2}$ nat. size.
FIG. 2.—Carbonised wood. Specimen B. Priestley Glacier. Nat. size.
FIG. 3.—Portion of a stem. Specimen C. Buckley Island. Nat. size.



H. G. Herring (Fig. 1)
& W. Tams, photo.
London Stereoscopic Co. imp.

Figs. 1, 2, Pieces of stems from the Priestley Glacier.
Fig. 3, Stem from Buckley Island.

PLATE II.

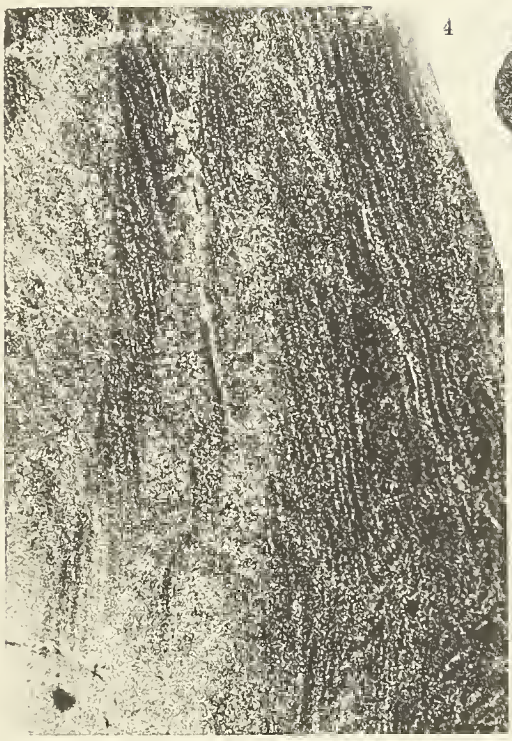
Fig. 4.—Section of a piece of wood from Buckley Island. Specimen D.

Fig. 5.—Section of wood from Buckley Island with structure almost obliterated. Specimen D.

Fig. 6.—Section of a piece of wood partially converted into impure bituminous "coal" resembling jet. from the Priestley Glacier. Specimen E.

Fig. 7.—Part of the same section more highly magnified.

Fig. 8.—Fragments of fronds of *Glossopteris indica*, and at V a piece of an axis doubtfully referred to *Vertebraria*. From Buckley Island. Nat. size.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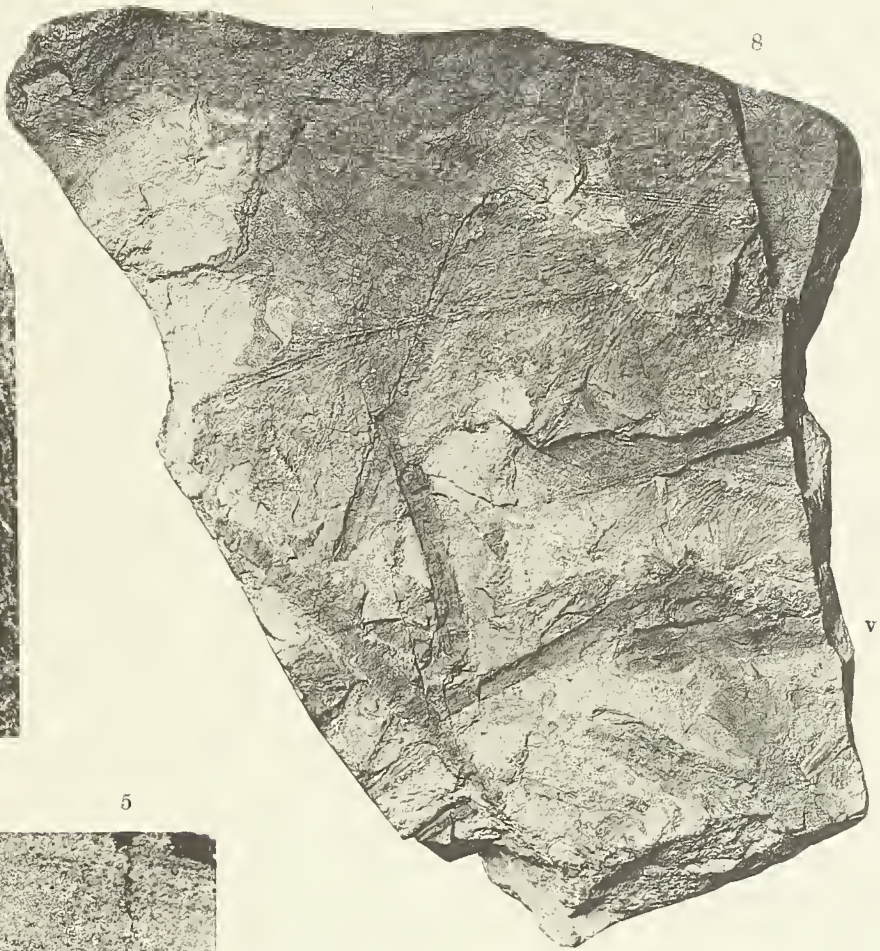
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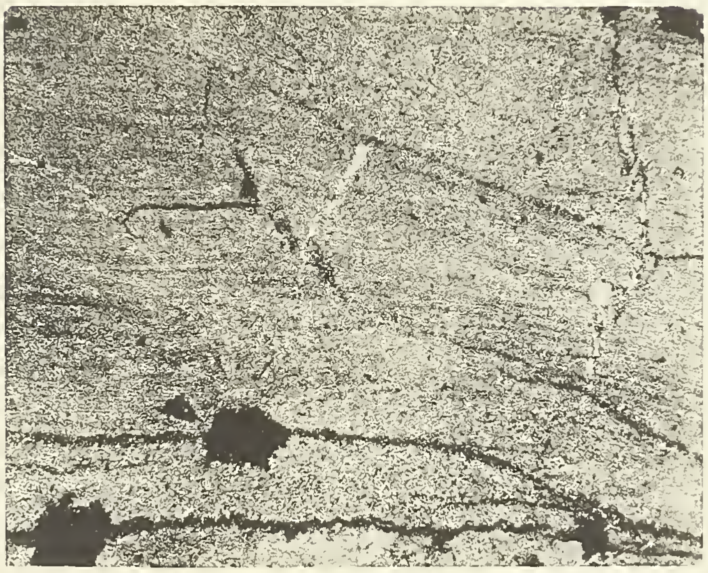
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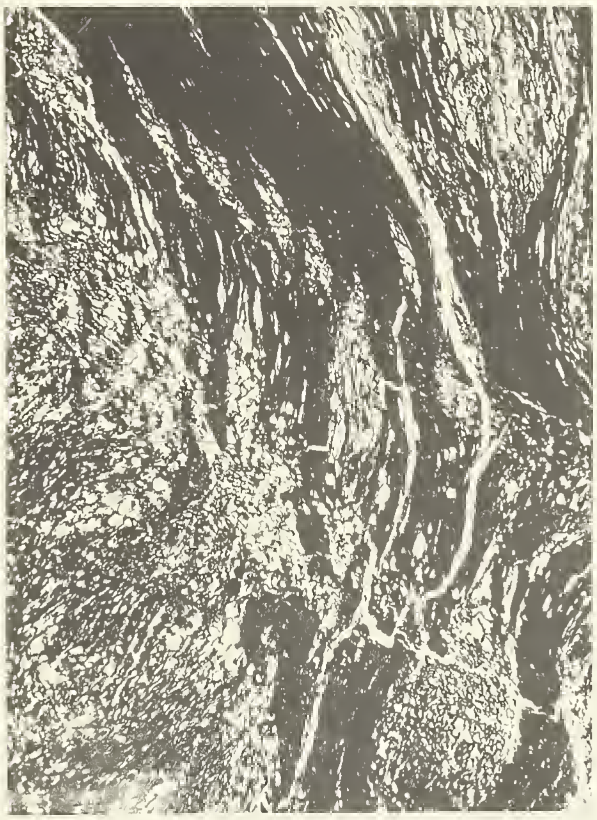
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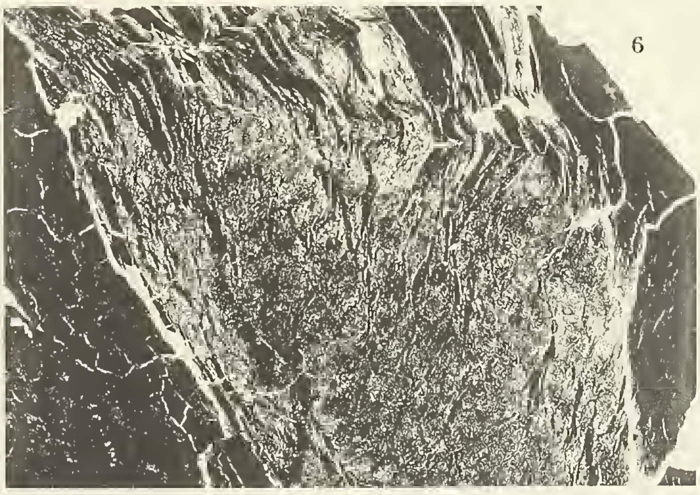
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W. Tams, photo. London Stereoscopic Co. imp.

Figs. 4, 5, Sections of wood from Buckley Island.
" 6, 7, Sections of wood from the Priestley Glacier.
Fig. 8, Glossopteris, from Buckley Island.

PLATE III.

Figs. 9, 9a.—*Glossopteris indica* Schimp., drawn from a piece shown in Fig. 8, Pl. II. Fig. 9, nat. size ; Fig. 9a. × 2.

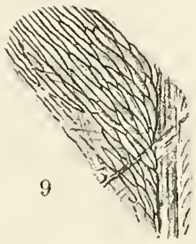
Figs. 10, 10a.—Probably a piece of *Vertebraria ;* shown at V in Fig. 8, Pl. II. Fig. 10a. × 2.

Figs. 11–14.—*Glossopteris indica* var. *Wilsoni*, var. nov., from Buckley Island. The enlarged drawings are all twice natural size.

Fig. 15.—? *Vertebraria.* From Buckley Island. Nat. size.

Figs. 16, 16a.—Possibly a fragment of a small scale-leaf of *Glossopteris.* Fig. 16a. × 2.

Figs. 17, 17a.—? Scale-leaf of *Glossopteris*, from Buckley Island. Fig. 17a. × 2.



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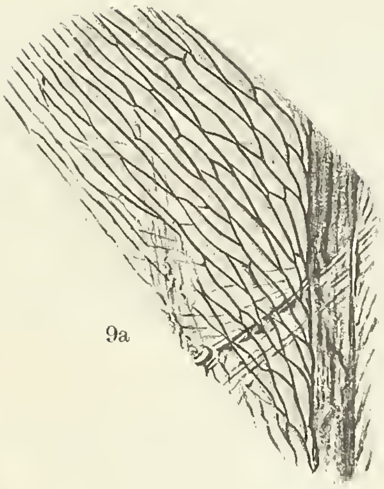

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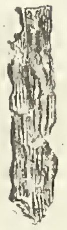

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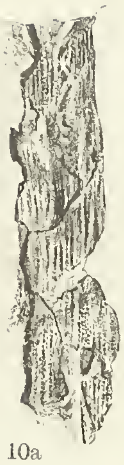

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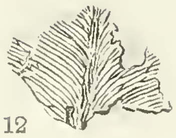

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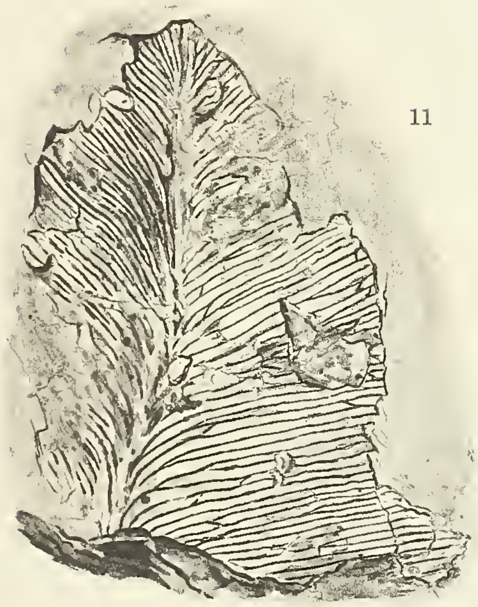

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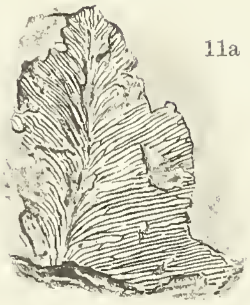

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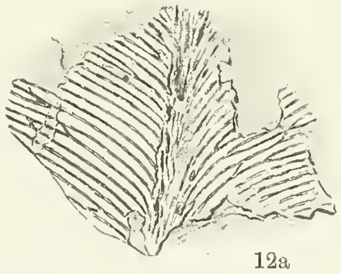

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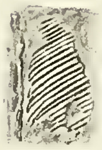

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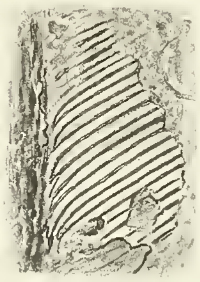

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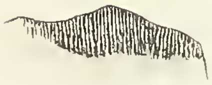

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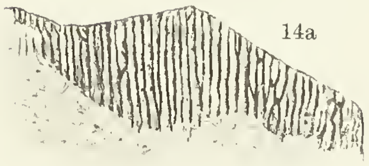

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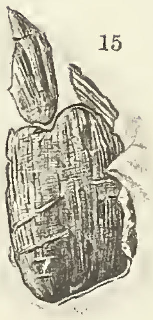

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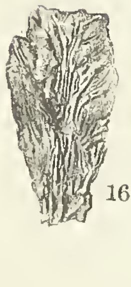

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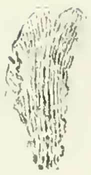

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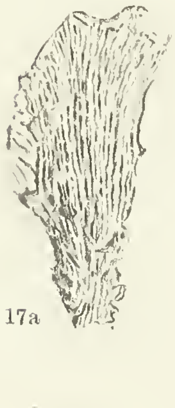


17a

T. A. Brock, del. [illegible]

Figs. 9, 9a, Glossopteris indica Schimp.
" 10, 10a, 15, ? Vertebraria sp.
" 11–14, Glossopteris indica Var. Wilsoni.
" 16, 17, ? Scale leaves of Glossopteris.

PLATE IV.—*Antarcticoxylon Priestleyi*, gen. et spec. nov.

Figs. 18, 18a.—Horizontal surface-view and tangential view respectively of a piece of the stem, natural size : *a*, *a*, leaf-traces ; *b*, *b*, light bands following the course of a ring of growth.

Fig. 19.—Surface-view of a piece of the stem showing two light bands corresponding in position to the two broad leaf-trace gaps seen at *a*, *a*, in Fig. 23.

Fig. 20.—Radial section ; *c*, line of fracture where the tissues are faulted ; at *d* the junction is shown between a leaf-trace and the secondary wood ; *p*, pith ; the junction of the trace, seen at *e*, with the secondary wood is shown in Fig. 34, Pl. VI. Section I.

Fig. 21.—Transverse section, natural size. *l′* a broad space in the outer part of the course of a leaf-trace corresponding to *a*, *a*, in Figs. 18 and 19 ; *l*, leaf-trace ; *l″*, position of leaf-trace enlarged in Fig. 38, Pl. VII. Section C.

Fig. 22.—The horizontal surface of the block shown in Fig. 19 ; the black border on the lower edge represents the foreshortened side of the block. *l*, *l′*, *l″*, leaf-traces. Nat. size.

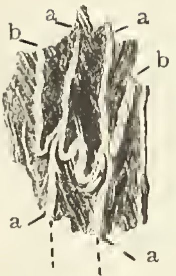
Fig. 23.—Transverse section, showing leaf-traces *l*, *l′* ; *a*, *a*, broad outer portions of leaf-trace tracks. *f*, position of leaf-trace shown on a larger scale in Fig. 42, Pl. VII. Section D, × 2.

Fig. 24.—Central part of Fig. 23 showing rings of growth, pith, and leaf-traces. Section D, × 6.

Fig. 25.—Transverse section, showing leaf-trace *a*, *l*, and one of the broad light bands, *b*, *b*, in the xylem. Section B, × 8.

Brit. Antarctic (Terra Nova) Exped. 1910.

Brit. Mus. (Nat. Hist.) Geology. Plants, Pl. IV.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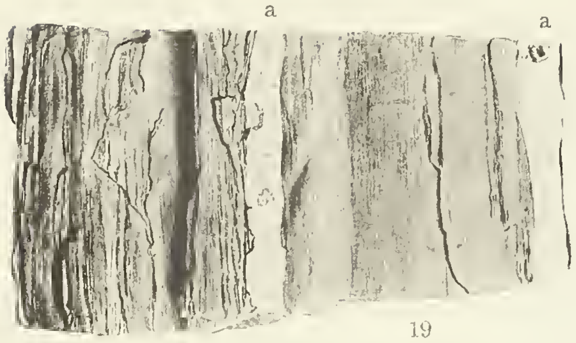
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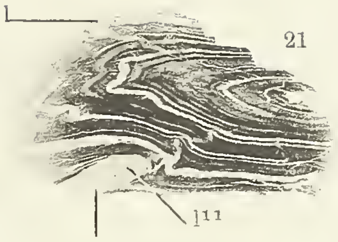
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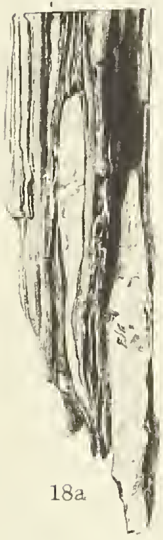
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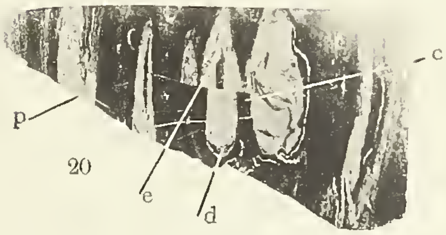
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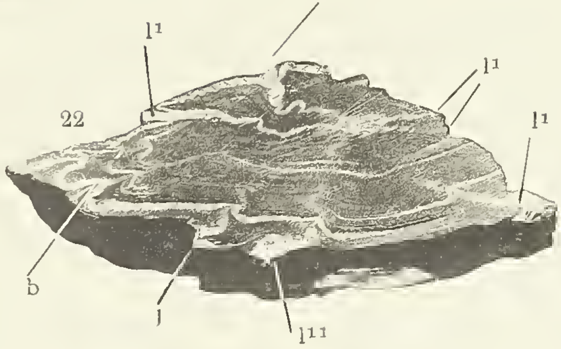
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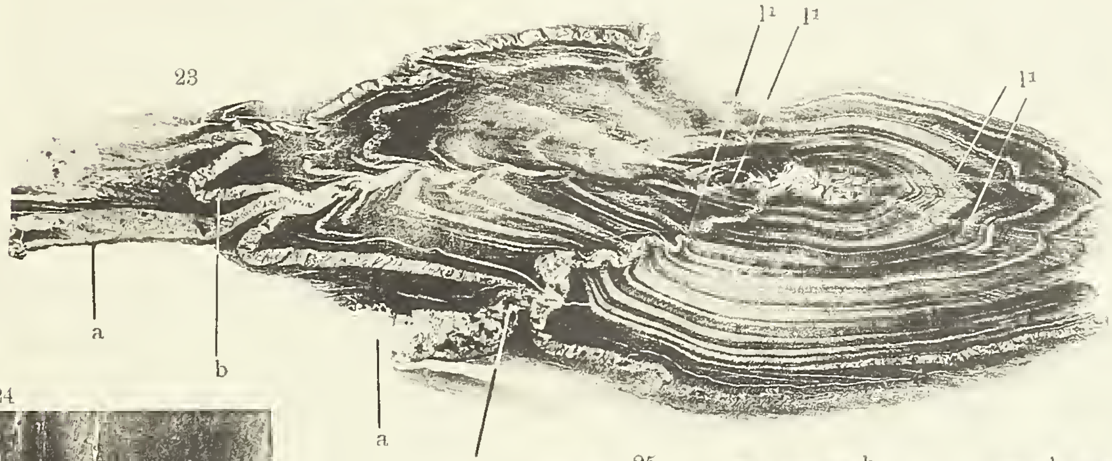
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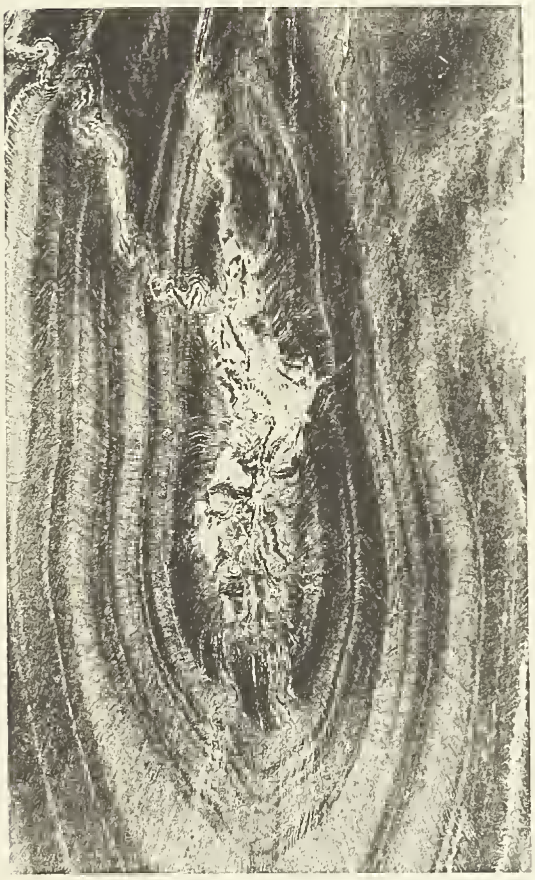
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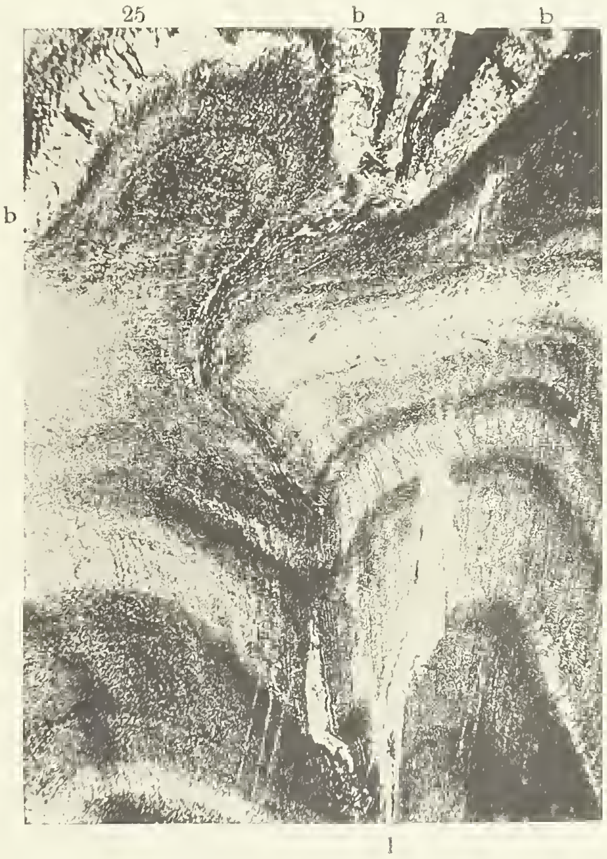
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T. A. Brock, del. (Figs 18, 19.)
W. Tams, photo.

Antarcticoxylon.

PLATE V.—*Antarcticoxylon Priestleyi.*

Figs. 26, 27.—Transverse sections, showing a broad ring of growth (Fig. 26) and one of the light bands (Fig. 27) formed in part by the destruction of secondary wood. Section C.

Fig. 28.—Secondary xylem, with medullary rays represented by spaces. Section D.

Fig. 29.—Tangential section of the secondary xylem. Section H.

Figs. 30, 31.—Spiral tracheids in the pith. Section G.

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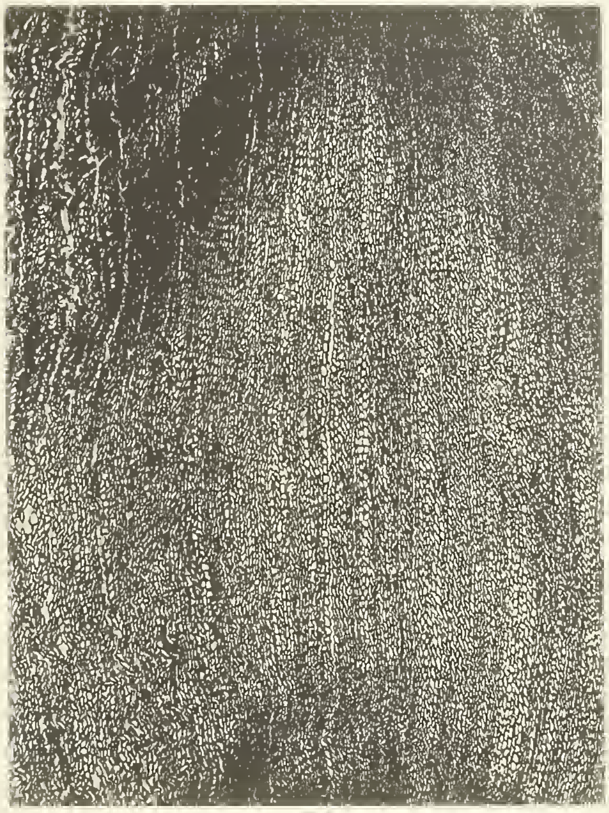

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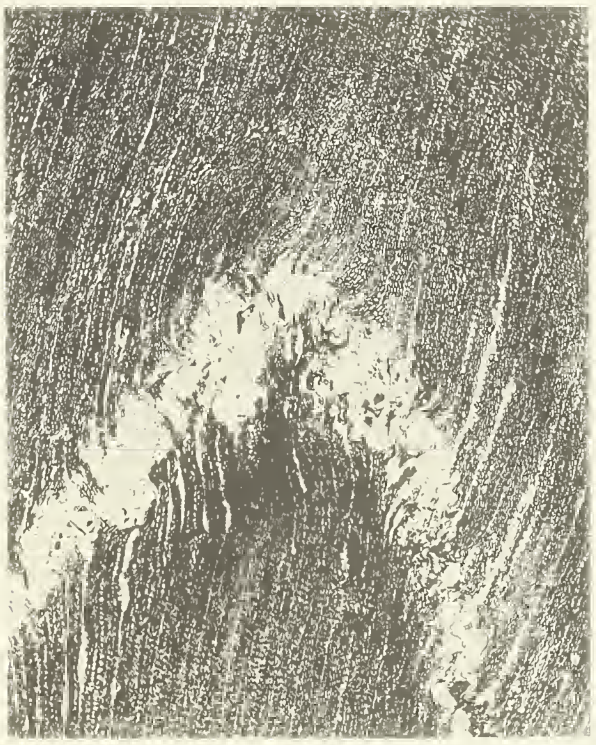

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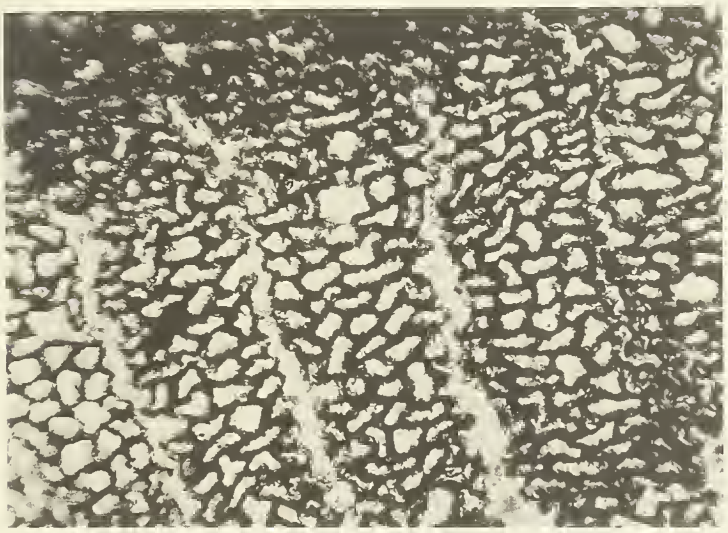

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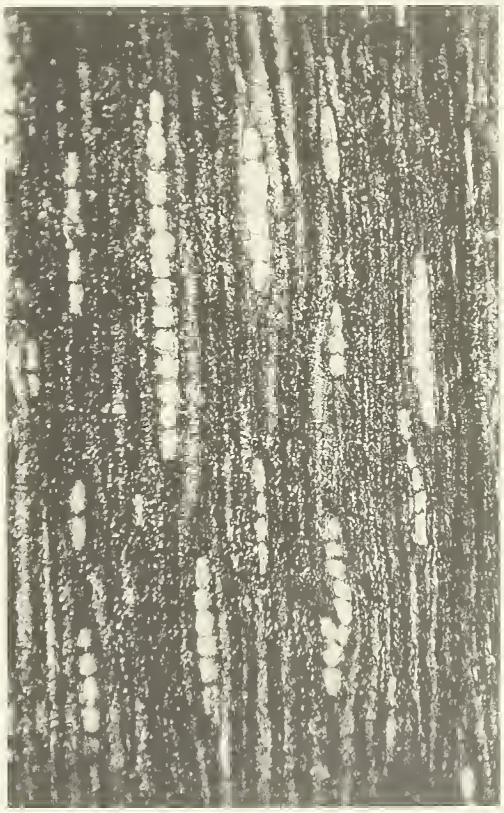

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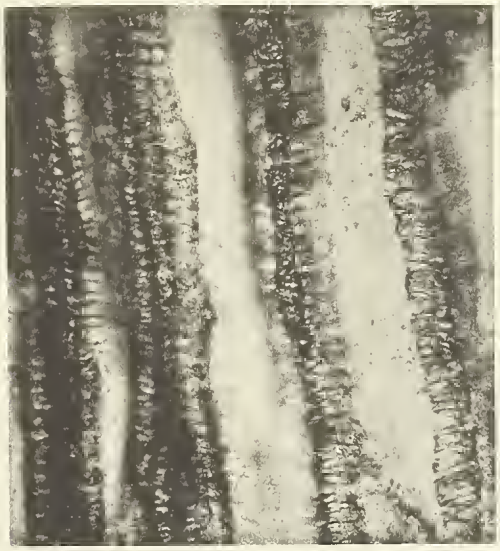

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W. Tams, photo. London Ste [illegible]

Antarcticoxylon

PLATE VI.—*Antarcticoxylon Priestleyi.*

FIG. 32.—Tangential section of the secondary xylem. Section I.

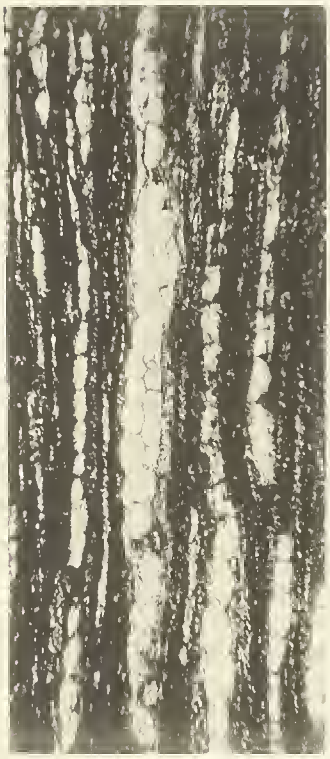
FIG. 33.—Radial section of the secondary wood showing imperfectly preserved pits. Section I.

FIG. 34.—Longitudinal section, showing a leaf-trace joined below to the secondary xylem; *t*, short tracheids. Section I.

FIG. 35.—Pith in longitudinal section. Section G.

FIG. 36.—Radial section of secondary wood showing a double row of pits. Section I.

FIG. 37.—Branched leaf-trace accompanied by parenchyma, *pr.*, and joined below to the secondary wood. Section F.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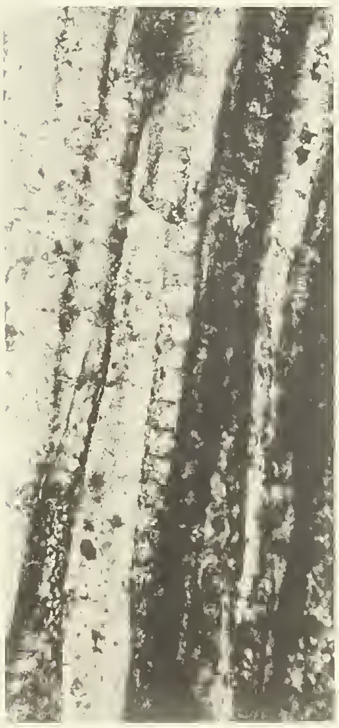
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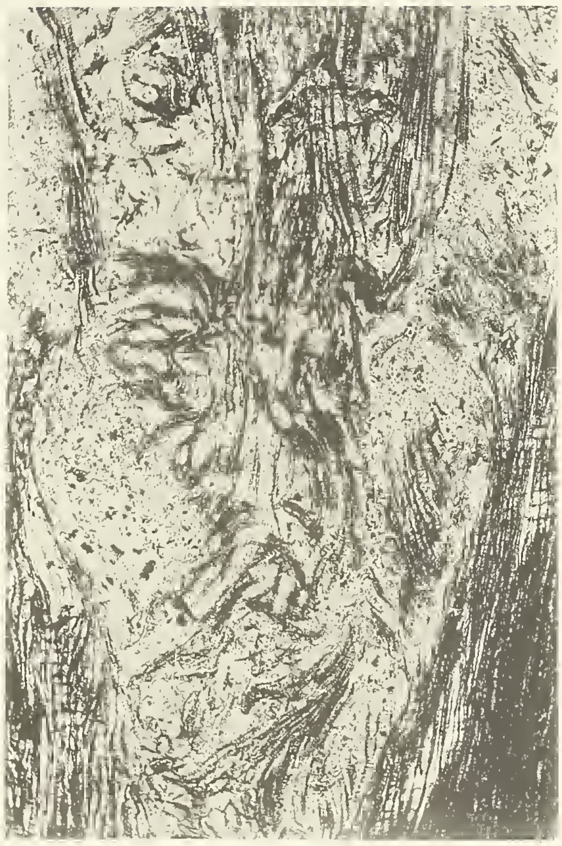

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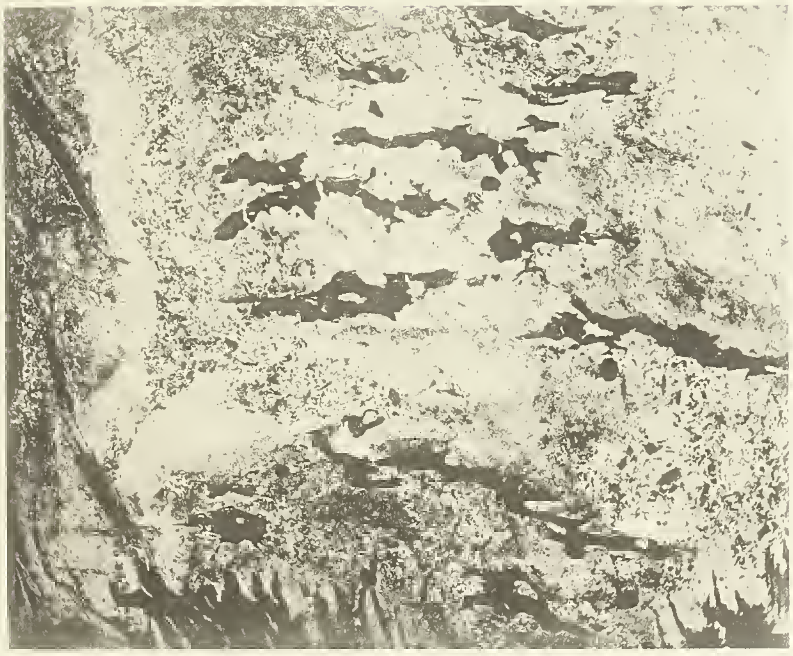
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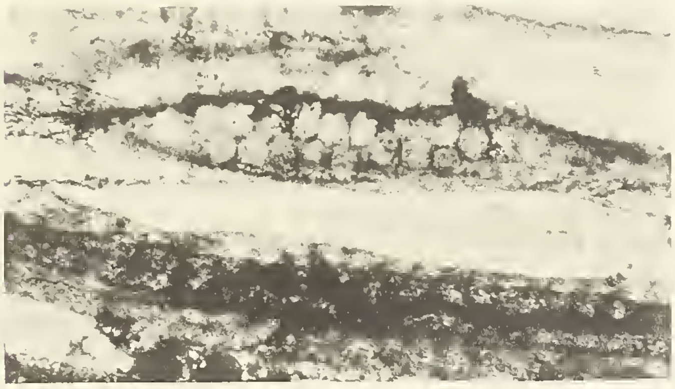
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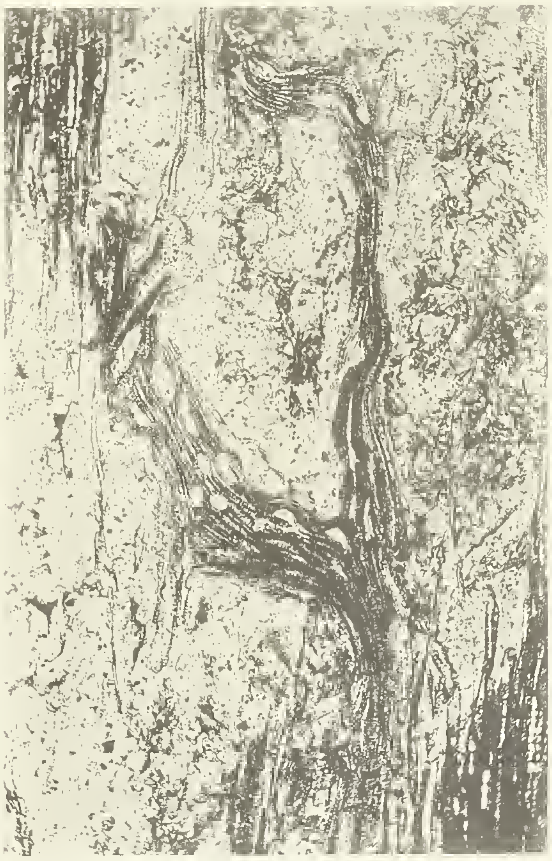

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W. Tams, photo.

London Stereos. [illegible]

Antarcticoxylon

PLATE VII.—*Antarcticoxylon Priestleyi.*

Fig. 38.—Leaf-trace from *l* in Fig. 21, Pl. IV. Section C.

Fig. 39.—Parenchyma in the neighbourhood of the trace shown in Fig. 38. *Cf.* Fig. 45*, Pl. VIII.

Fig. 40.—Leaf-trace strands with crushed parenchyma and, on the right hand side edge, secondary wood. Section F.

Fig. 41.—Leaf-trace xylem strand in the pith. Section E.

Fig. 42.—Leaf-trace from *f*, Fig. 23, Pl. IV. Section D.

Fig. 43.—Short tracheids in close association with long spiral tracheids in the pith. Section E.

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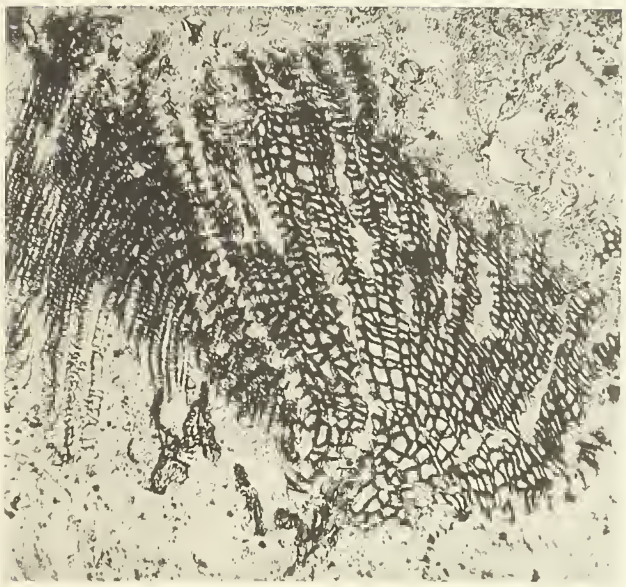

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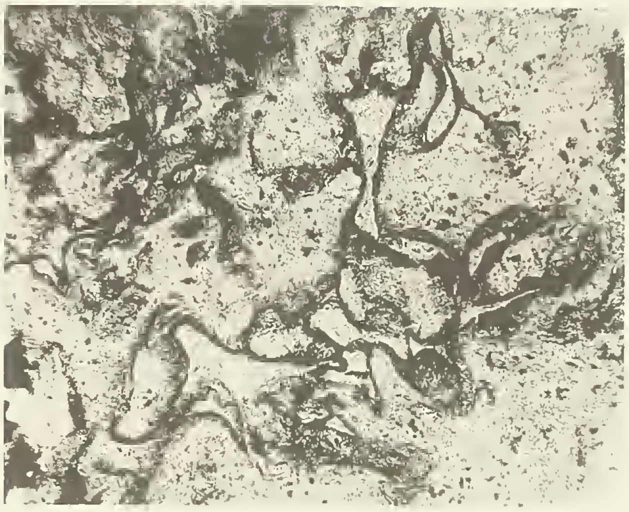

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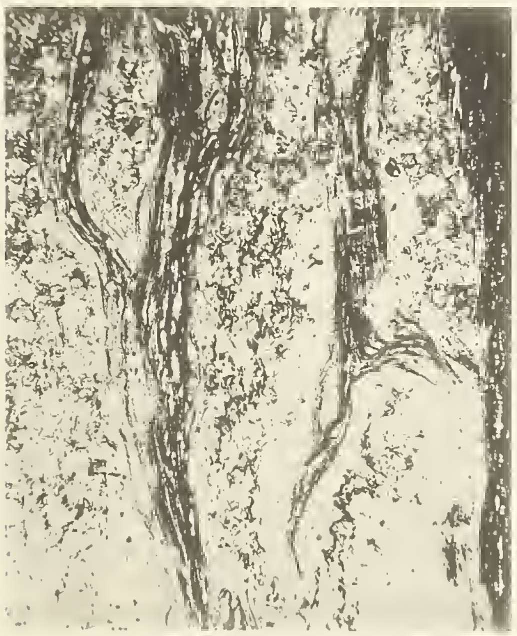

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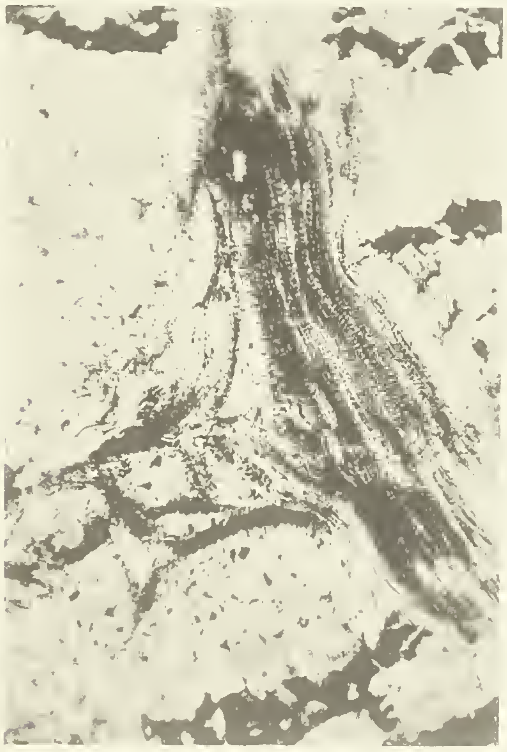

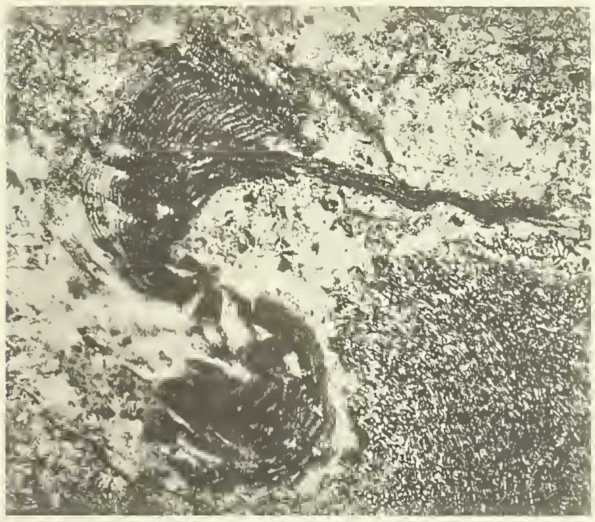
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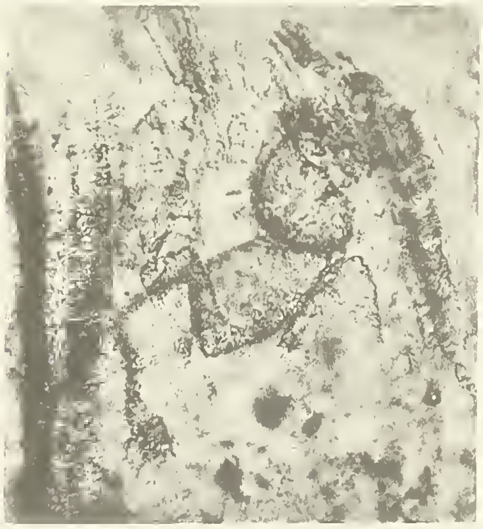

W. Tams, photo. [illegible]

Antarcticoxylon

PLATE VIII.—*Antarcticoxylon Priestleyi* and (Fig. 45) *Pityosporites antarcticus.*

FIG. 44.—Transverse section showing part of the xylem tissue at the edge of the pith; x', x', crushed primary xylem; a, small tracheids simulating protoxylem. Section N.

FIG. 45.—*Pityosporites antarcticus.* From the pith of the *Antarcticoxylon* stem, shown in Fig. 46 at s. Section N.

FIG. 45*.—Branched cell in the pith; s, part of the contents of some secretory cells. Section G.

FIG. 46.—Part of the pith; the pollen-grain was found at s, just outside the figured area, near one end of the long axis of the pith. Section N.

FIG. 47.—A leaf-trace in longitudinal section, approximately 1 mm. broad. Section P.

FIG. 48.—A portion of one of the broad light bands, b, in the secondary xylem (*cf.* Fig. 27, Pl. V.) showing partially decayed xylem connecting the two sides of the band. Section O.

FIG. 49.—A portion of the secondary xylem bordering the pith; px, probable position of the protoxylem; x^2, displaced secondary tracheids. Section N.

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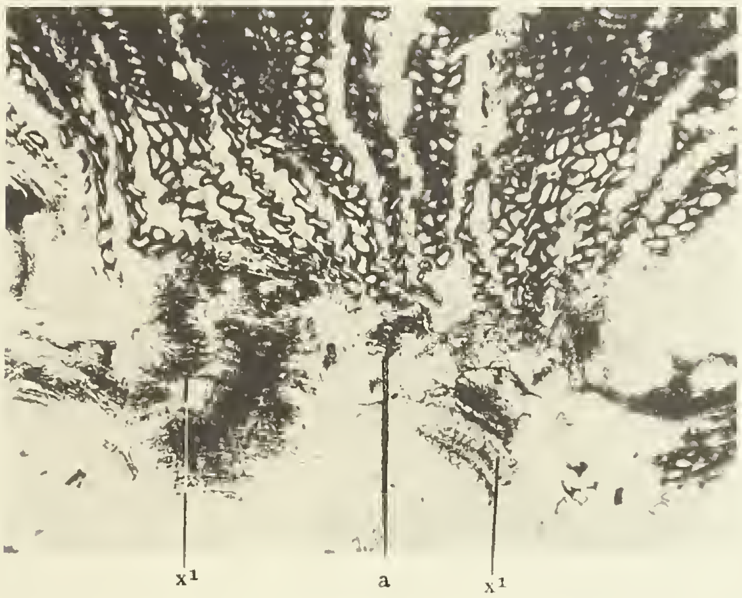

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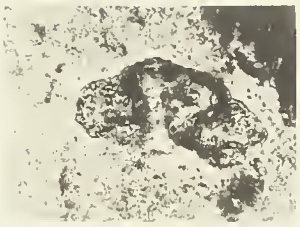

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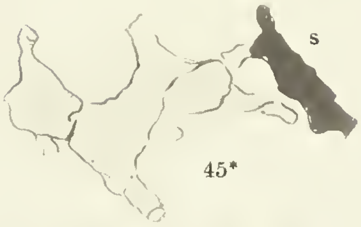

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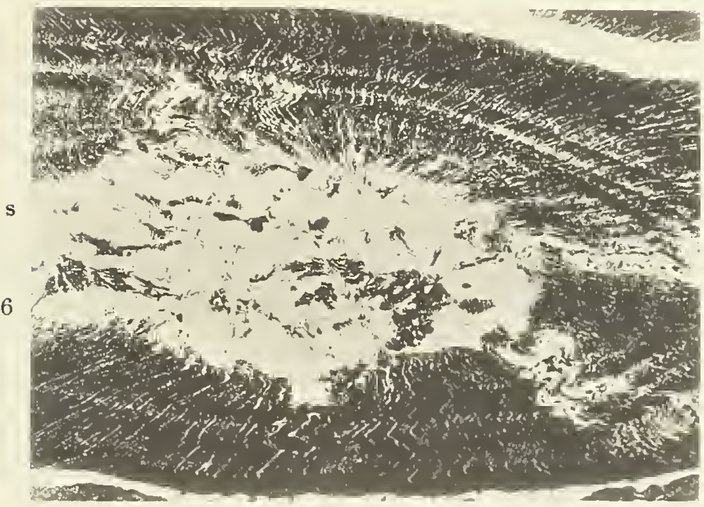

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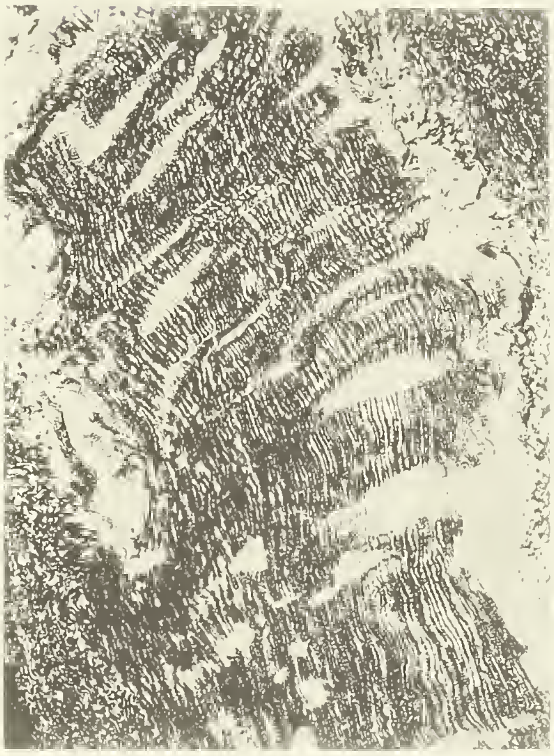

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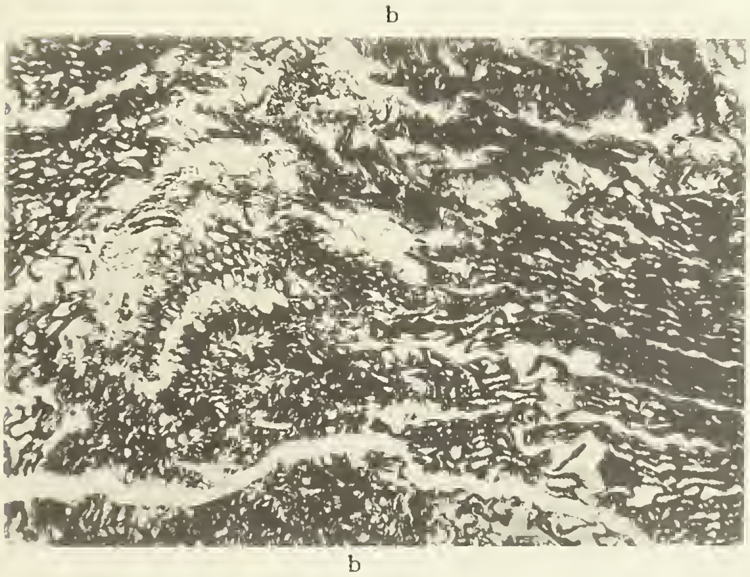

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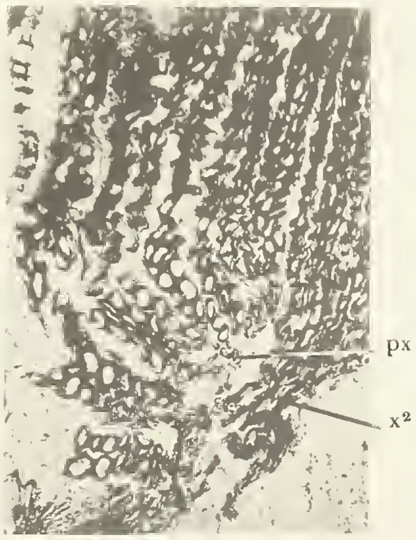

W. Tams, photo.

Antarcticoxylon

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BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910.

NATURAL HISTORY REPORT.

GEOLOGY. VOL. I, No. 2. Pp. 51-62.

FISH-REMAINS FROM THE UPPER OLD RED SANDSTONE OF GRANITE HARBOUR, ANTARCTICA.

BY

ARTHUR SMITH WOODWARD, LL.D., F.R.S.

WITH ONE PLATE.

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FISH-REMAINS FROM THE UPPER OLD RED SANDSTONE OF GRANITE HARBOUR, ANTARCTICA.

By ARTHUR SMITH WOODWARD, LL.D., F.R.S.

WITH ONE PLATE.

THE fish-remains discovered by Mr. Frank Debenham in the "Beacon Sandstone" of Granite Harbour, are merely dermal plates and scales. They are all isolated and scattered, showing that the fishes they represent were disintegrated before burial; but the fragments are beautifully preserved, and in transparent sections their histological structure is perfectly observable. They are very little mineralised, and the cavities, at least in weathered portions, are often empty. The specimens are usually conspicuous as whitish or bluish-grey patches on the grey or blackish rock, though a few are darkly stained.

SUB-CLASS OSTRACODERMI.

ORDER ANTIARCHI.

Numerous typical fragments of the dermal armour of Ostracoderms are easily recognisable, and all appear to belong to the Order Antiarchi. Some are not sufficiently characteristic or well-preserved for exact determination, but others may be referred at least to their respective genera without much hesitation.

Seven portions of keeled plates of uncertain outline, besides other fragments, exhibit the peculiar structure of Antiarchan armour—an outer dense tuberculated layer, a middle thick layer of cancellæ, and an inner thin layer of parallel laminæ. One of these specimens, P. 12535* (Fig. 1), which has lost much of its tissue both externally and internally, shows a thickening in the middle of the cancellated layer in the hollow of the keel and an arrangement of the cancellæ in roughly transverse lines, evidently to strengthen the plate at the bend. When viewed in cross-section (Fig. 1A) the cancellæ appear to be very variable and irregular in size, and as seen under the microscope the walls between them are comparatively thin, consisting of a few delicate parallel laminæ. In another specimen (P. 12536) the walls between the cancellæ are relatively thicker, and there are traces of bone-cells between the laminæ. In a third specimen (P. 12537) embedded in hard rock, the cavities are infiltrated with calcite and the bone is too darkly stained to be clear, but all the layers of the shield are distinctly recognisable (Fig. 2) in their characteristic arrangement. Below the thin dense outer layer, which rises at intervals into rounded tubercles, there is a zone of small cancellæ with relatively thick walls; below this is a zone of larger cancellæ with delicate walls; and finally there is a thin inner or basement layer of parallel laminæ. Traces of bone-cells are seen between the laminæ of the plate throughout. A similar arrangement of the successive layers of the shield is also well shown in the broken section of another fragmentary specimen (P. 12538).

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* The numbers refer to the Register Pisces of the Department of Geology.

Bothriolepis antarctica, sp. nov. Figs. 3–9.

The structure of the two Ostracoderm plates last described agrees most closely with that of *Bothriolepis*,[*] and several fragments in the collection may certainly be referred to this genus.[†] They include both parts of the head and trunk and plates of the appendages.

A right *lateral occipital plate* (P. 12543) is nearly complete, and shown of twice the natural size in Fig. 3. The greater part of the corresponding plate of the opposite side is also preserved on another piece of rock (P. 12544). It is a little wider than long, the maximum width being about 11 mm., while its maximum length is 9·5 mm.; and its anterior margin is angulated somewhat nearer to the external than to the internal margin. Its outer face is completely covered with an ornament of coarse rounded tubercles, which are united into a network by lower rounded ridges; and the stronger of these ridges tend to form transverse lines on the antero-external part of the plate. A groove for a slime-canal (*l*), close to and nearly parallel with the external margin, is seen in the slightly broken postero-external part. As this groove does not run into a transverse groove, or commissure, but merely passes out at the posterior margin, the arrangement corresponds with that of *Bothriolepis* and differs from that observed both in *Asterolepis* and *Pterichthys*.

An impression of the outer face of a left *anterior ventro-lateral plate* of the trunk (Fig. 4) is only imperfect near the median border and just above the articulation for the appendage (P. 12545). Its maximum length is 18 mm., the maximum width of the horizontal lamina is 8 mm., and the maximum depth of the ascending lamina is 4 mm. The plate is shown to have been completely covered with reticulated ridges, producing a coarse ornament of pits, which only exhibit a tendency to arrangement in lines close to and concentric with the anterior margin. The low lateral ascending lamina is inclined outwards, making an angle greater than a right-angle with the horizontal lamina ; and its upper border bears the mark of the narrow overlap of the anterior dorso-lateral plate. The articulation for the appendage, seen in cross-section (*ar*), is within the anterior third of the plate. The anterior margin of the horizontal lamina has a forwardly convex curvature, and the antero-median angle of the plate is sharply truncated where it adjoins the *semilunar*. The upper margin of the ascending lamina curves downwards to meet the posterior margin of the horizontal lamina in an obtuse angle.

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[*] For the most exhaustive account of *Bothriolepis*, see R. H. Traquair, "Fishes Old Red Sandst. Britain" (Pal. Soc. 1904, 1906), pp. 107–131, with plates.

[†] E. S. Goodrich, in Lankester's "Treatise on Zoology," Part IX (1909), p. 206, fig. 180.

The outward inclination of the ascending lamina of the plate just described, and the inferred shape of the *semilunar*, are distinctive characters of *Bothriolepis ;* while the external ornament is that usual in this genus.

Remains of the articular portion of a larger right *anterior ventro-lateral plate* (P. 12546) also show a characteristic feature of *Bothriolepis*. The specimen (Fig. 5) is so much fractured that it is not easily interpreted, but by direct comparison with the front half of a right anterior ventro-lateral plate of *Bothriolepis major* in the British Museum (No. P. 8282*a*) the parts can be recognised. The wide rounded groove (*g*) to accommodate the dorsal articular plate of the appendage, is overhung by a mass of cancellated tissue (*t*) in which the rather large chambers are elongated and arranged in lines at right-angles to the articular face. This mass is exposed in a transverse section, which also cuts across the inner continuation of the canal (*c*) penetrating the articular prominence. Round, below, and internal to the canal, the tissue becomes very finely cancellous, and some of it is darkly stained in the fossil. So far as preserved, the coarsely cancellated mass of tissue above the articulation is exactly similar to that of *Bothriolepis*, while differing from the denser and smaller mass in *Pterichthys* and *Asterolepis*.

A left *posterior ventro-lateral plate* (P. 12547), with a maximum width of 21 mm. and a total length of not less than 50 mm., is preserved in counterpart and variously fractured to expose the different layers of which it consists (Figs. 6, 6A). Part of the outer face shows the reticulate ridges producing the characteristic coarse pitted ornament. Below this are traces of the layer of polygonal chambers, resting on the very thin layer of fine parallel calcified ridges which run obliquely backwards from the internal or median margin to the external or lateral margin of the plate. Below this again the inner face is formed by the laminated nacreous layer. As in the typical *Bothriolepis*, the ascending lateral lamina is inclined at slightly more than a right-angle to the horizontal lamina. The truncation of the antero-internal angle of the horizontal lamina indicates the presence of a large diamond-shaped *median ventral plate ;* but the margins are imperfect.

Part of another left *posterior ventro-lateral plate* (P. 12548) also shows the ascending lateral lamina inclined as in *Bothriolepis*. The broken sections of the specimen exhibit all the characteristic features of Antiarchan armour.

A crushed left *ventral articular plate* of an appendage (P. 12549) is exposed from the inner face and displays the characteristic shape and texture of the proximal end, which measures about 10 mm. across (Fig. 7). This rounded end consists, as usual, of a close series of fine laminæ nearly parallel with the long axis of the bone and united by cross-structures. Below this articular portion the inner margin is sharply notched. The other margins are incomplete.

An impression of the inner face of another articular plate of an appendage, of about the same size, exhibits two strongly marked ridges, one extending transversely below the rounded head, the other passing downwards from this along the vertical median line. This specimen (P. 12550) may represent the *dorsal articular plate*, but the determination is uncertain.

The distal portion of a left *ventral anconeal plate* of an appendage (P. 12551) is shown from within in direct articulation with the adjoining part of the *external marginal* (Fig. 8). An impression of the outer face of the anconeal plate (*a*) proximal to the piece preserved, proves that it was ornamented externally by coarse longitudinal ridges, with a few irregular cross-ridges, producing a reticulated ornament. The large rounded distal end, which formed the movable articulation for the terminal segment of the appendage, consists of fine parallel plates or fibres which run obliquely backwards and outwards. It measures 6 mm. in extreme width. The external marginal (*m*) is fringed along the outer border with a row of large tubercles, which are apparently uniform in size and spacing. Its width at the distal end is 3·5 mm. The external ornament appears sufficient to justify the reference of this specimen to *Bothriolepis*.

A *proximal external marginal* of the distal segment of an appendage (P. 12552) lacks only its distal end (Fig. 9). Its maximum width at the proximal end is 5·5 mm., and its total length would be about 17 mm. At the obliquely truncated proximal end of the plate the finely cancellated tissue of the overlapped portion is preserved, but the other portion is shown only in impression. The outer face is clearly marked by a few irregular longitudinal ridges, while the externo-lateral border bears a row of large blunt tubercles. The ridged ornament is characteristic of *Bothriolepis*, the corresponding part in *Pterichthys* and *Asterolepis* being tuberculated.

The plates of *Bothriolepis* thus described obviously belong to specimens of various sizes. The anterior ventro-lateral plate (Fig. 4), for example, is too small to belong to the same individual as the posterior ventro-lateral plate (Fig. 6). There is, however, no reason why they should not all belong to one species, and they may be provisionally so regarded. The shape of the lateral occipital plate (Fig. 3), with its sharply angulated anterior margin, is a little different from that in the head of any species of *Bothriolepis* hitherto known. It therefore probably represents a new species, which may be named *B. antarctica*.

Byssacanthoides debenhami, gen. et sp. nov. Figs. 10, 11.

Some fragments of a ribbed spine exhibit much superficial resemblance to *Onchus*, but are readily distinguished by their microscopical structure. They are, indeed, most nearly similar to the spine on the posterior dorsal plate of the Antiarchan Ostracoderm, *Byssacanthus*.[*]

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[*] A. S. Woodward, Ann. Mag. Nat. Hist. [6], Vol. XV (1895), p. 142, with text-fig.

The largest specimen (P. 12553), which is sharply broken at each end, measures 1 cm. in length and maintains an approximately uniform diameter of 2 mm. It is round in cross-section, and the irregular longitudinal fracture of the specimen exposes a large internal cavity filled with matrix (Fig. 10). The outer face is marked with fine, smooth, straight, longitudinal ribs, which are closely arranged and parallel, rarely intercalated.

The superficial longitudinal ribs appear to be the outer edges of thin wedge-shaped radiating plates of which the tissue of the spine is composed. These are still better seen in another fragment (P. 12555), which is weathered ; and their structure is perfectly preserved in a third specimen (P. 12554), which is sufficiently hard to be studied in microscopical section (Fig. 11).

The outer layer of the spine (*o*), when viewed in transverse section, is seen to be denser than the rest of the tissue, but it appears to be partly removed in the specimen figured. It contains irregular vascular spaces, and the tissue itself is traversed by a network of extremely fine irregular tubules, occasionally expanded into spaces which may have been occupied by bone-cells. The zone of wedge-shaped plates (*w*) is sharply marked off from this outer layer, and forms the greater part of the thickness of the side of the spine, but is much reduced in the anterior middle portion. Each wedge is separated from its fellow by extensive but irregular vascular spaces, and its tissue in transverse section is seen to be not only traversed by the network of very fine tubules already noted in the outer layer, but is also marked by a few dark transverse bands which are nearly parallel with the outer face. The zone of wedge-shaped plates is also sharply marked off by a dark line from the inner layer (*i*), which is thickest in the middle part of the spine and is traversed by very large and irregular vascular spaces, which are seen to communicate with the pulp-cavity (*p*). The tissue of this layer again is traversed by a network of extremely fine tubuli, and each wall between the vascular spaces is darkest or densest in its middle portion.

In the fragment from which the microscope-section has been prepared, the pulp-cavity is widely open behind, and the spine does not appear to have been bilaterally symmetrical. It is therefore presumably from the base of a spine which differs considerably from that of *Byssacanthus*, where the lower end is completely closed. In transverse section, however, the new specimen agrees remarkably well with the spine of *Byssacanthus* in the appearance of the three layers of which it is composed ; and it differs completely from that of *Onchus*, in which there are no wedge-shaped plates, while the inner layer is dense and to some extent finely laminated.* *Onchus*, it may be added, is also typically Elasmobranch in exhibiting no trace of bone-cells. The spine which is so imperfectly known, therefore, probably represents a new Antiarchan genus, *Byssacanthoides*, and the species may be named *debenhami*, in honour of its discoverer.

---

* J. V. Rohon, Mém. Acad. Imp. Sci. St. Pétersb. [7], Vol. XLI, No. 5 (1893), p. 42, fig. 9.

SUB-CLASS ELASMOBRANCHII.

ORDER ACANTHODII.

Cheiracanthus, sp. Fig. 12.

Two isolated scales are evidently Acanthodian, and so closely similar to those of the typical *Cheiracanthus murchisoni* from the Middle Old Red Sandstone of Scotland, that they may be provisionally referred to the same genus. The best-preserved specimen (P. 12576) is shown to be square and slightly more than a millimetre in diameter (Fig. 12). Its outer face is shiny, and a close series of fine, regular, nearly parallel grooves extends diagonally across two-thirds of this face from the two posteriorly directed borders, which are distinctly bevelled, but not crimped or serrated. The second specimen, though more imperfect, is evidently similar.

Acanthodian scales* are also recognisable in microscope-slides of the rock, and a characteristic specimen in transverse section (P. 12559) is shown in Fig. 13. The outer face of this scale is flat, and one end is produced considerably beyond the supporting base. The deep exserted portion exhibits well its concentric laminated structure, traversed in places by a few irregular branching canaliculi. The shape of the comparatively small rounded base, which was originally inserted in the skin, is also distinct; but its structure is obscured by a dense stain of mineral matter. As usual, there is no pulp-cavity.

ORDER SELACHII (?).

Dermal tubercles. Figs. 14–22.

Minute fragments of dermal armour are scattered abundantly through various specimens of the rock, but most of them are shown only in broken section and so cannot easily be identified. Some are evidently fragments of dermal plates or scales, but the majority seem to be shagreen-granules referable either to primitive Ostracoderms or to Elasmobranchs.

Some granules of various shapes exhibit a relatively large pulp-cavity. The broken transverse section of an oval specimen (Fig. 14) bears a trace of three prominences or flutings on one side (P. 12589). A similar section of a smaller rhombic specimen (Fig. 15) exhibits a fluting or sinuosity on two contiguous sides (P. 12561). Another specimen appears in transverse section (Fig. 16) as an irregular elongated rhomb (P. 12590). A fourth specimen, apparently in vertical section (Fig. 17), rises to an acute apex, which is nearer to one margin than to the other (P. 12563). Another specimen which seems to be similarly displayed (Fig. 18) is low and flattened.

The majority of the shagreen-granules are solid, and in section exhibit only a slight trace of the obliterated pulp-cavity. Several occurring in a group on one piece of rock

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* See O. M. Reis, "Ueber *Acanthodes Bronni* Agassiz," Schwalbe's Morphol. Arbeiten, Vol. VI (1896), p. 184, Pl. VII, fig. 2; also E. S. Goodrich, in Lankester's "Treatise on Zoology," Part IX (1909), p. 188, fig. 157.

(P. 12561) are shown enlarged in Fig. 19. Though irregular in shape, most of them approach a quadrangular form with variously indented sides. The last trace of the pulp-cavity is sometimes observable, sometimes it is marked by a slight stain.

In the same group is the only specimen which appears to exhibit the external face. It is smooth and crossed by two shallow parallel grooves which divide it into a large median lobe and two comparatively small lateral lobes (Fig. 20). This suggests a compound granule, such as occurs in the Upper Devonian *Cladoselache*[*] and in many of the early Selachians.

It is difficult to prepare sections of these fossils, but in one microscope-slide (P. 12562) there are two granules evidently produced by the fusion of cusps. The best of these (Fig. 21) shows a small expanded base surmounted by two cusps, which are fused together for some distance, and then diverge in two planes at the apex so that the section is incomplete. A third and smaller cusp, doubtless fixed to the same base, is seen at one side. The microscopic structure is typically Elasmobranch, each large cusp showing a trace of an original pulp-cavity from which fine calcigerous tubes radiate to the periphery, while coarser tubes diverge into the upper part of the base, and the lower part of the base exhibits only a concentric structure. The second specimen (Fig. 22) seems to be cut in more oblique section, so that the expanded base is relatively large and the four constituent cusps are less well separated. The structure is again seen to be typically Elasmobranch, but that of the base is somewhat obscured by a dark mineral stain.

SUB-CLASS DIPNOI.

ORDER ARTHRODIRA.

Undetermined Coccostean. Figs. 23, 24.

Remains of Coccostean dermal plates occur, but all are too fragmentary for generic determination. The largest specimen (P. 12563) is shown, slightly enlarged, in Fig. 23, with part of the ornament further enlarged in Fig. 23A. It is a thin flat plate embedded in hard dark shale, but its shape is uncertain, only part of one margin being clearly distinguishable. This margin seems to have been thickened throughout its extent by a broad rounded ridge, of which a fragment remains at its convex bend (*r*). The outer face of the plate is closely ornamented with stellate tubercles, which are nearly uniform in size but somewhat variable in shape, though all tending to be bluntly pointed. They are continued over the rounded marginal ridge, where their broken transverse sections exhibit a very small pulp-cavity.

A second fragment in black shale (P. 12564) is of a bent or ridged plate, also closely and coarsely ornamented with stellate tubercles (Fig. 24). It is exposed from within,

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[2] B. Dean, Mem. Amer. Mus. Nat. Hist., Vol. IX (1909), p. 214, figs. 1–3.

and so broken as to display the main trabeculæ of the middle layer of the plate extending at right-angles across the angulation.

A smaller plate (P. 12565) in the grey sandstone, also ornamented with large bluntly-pointed tubercles, has a gently convex outer border and an obtusely angulated inner border, suggestive of one of the paired ventral plates of the trunk. Where the outer surface is broken away, the fine longitudinal trabeculæ of the inner tissue are exposed.

Another fragmentary mass of coarsely fibrous tissue (P. 12566) in the grey sandstone, is also almost certainly Coccostean, and indicates a thicker plate than the specimens previously described.

SUB-CLASS TELEOSTOMI.

ORDER CROSSOPTERYGII.

Holoptychius antarcticus, sp. nov. Figs. 25, 26.

A small Holoptychian fish is represented by a few imperfect scales, which exhibit their characteristic microscopical structure. The best specimen (P. 12573) is shown of twice the natural size in Fig. 25. This scale is much longer than deep, ovoid in shape, and gently concave on its inner or attached face. It is widest in its overlapped portion, which is much larger than the exposed portion, and the division between these two portions is marked by a slight notch in one margin. The tissue when broken as in the fossil displays the concentric lines of growth ; and the dense inner layer, of which merely a fragment remains at the anterior end of the specimen, has a smooth face marked only with a few fine vascular perforations. The outer layer of the scale, of which the greater part is preserved, is highly vascular, and at the anterior margin it shows its delicate radiating trabeculæ. Most of the hinder exposed portion of the scale is exhibited as an impression on the rock, indicating an ornament of numerous small rounded ridges directed mainly antero-posteriorly but partly reticulated near the lateral margin.

One good transverse section of a scale (P. 12574) has been made to show its microscopical structure (Fig. 26). The highly vascular outer layer is about as thick as the dense inner layer, and its chambers are very irregular in size and shape, though all rounded in section. The inner layer is laminated as usual, with nearly straight canaliculi crossing the laminæ, those of each lamina approximately parallel, but meeting at an angle the corresponding canaliculi of the lamina above and below—a feature specially characteristic of the Holoptychian scale.* Near one edge of the transverse section the inner layer is thickened into a low boss, which seems to have been formed round the canal of the lateral line.

On the same piece of rock as the scale shown in Fig. 25, there is a small fragment of bone marked with a delicate reticulate ornament suggesting that of the clavicle of *Holoptychius*.

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* M. Lohest, Ann. Soc. Géol. Belg., Vol. XV (1888), Mém., p. 128, Pl. II, fig. 4 : J. V. Rohon, Bull. Acad. Imp. Sci. St. Pétersb., n.s., Vol. II (1890), p. 1, pl. I.

The form of scale now described differs considerably from any Holoptychian scale hitherto known, and may be named *Holoptychius antarcticus*. In its shape and the extent of its overlapped portion, it agrees best with the scales of the species commonly referred to *Glyptolepis* ; but its exposed portion is more coarsely ornamented than in any of these species, and the tissue of the scale is apparently thicker.

Osteolepid. Figs. 27–29.

Some typically Osteolepid scales, showing their microscopical structure,* are not generically determinable, and an imperfect operculum or cheek-plate, evidently of the same fish, is equally unsatisfactory. The smooth, shining outer surface of these fossils is very finely and regularly punctate, as in the Middle Devonian *Osteolepis*, *Diplopterus*, and *Thursius* ; but most of the scales are larger than those of the known species of these genera, and are at least equal in size to those of the Lower Carboniferous *Megalichthys laticeps*.

Two of the largest scales (P. 12576) in the hard black shale from Granite Harbour belong to the lateral line, and are shown enlarged in Figs. 27, 28. In both, the margin of the anterior overlapped portion is preserved, displaying the acute antero-superior angle, the convex edge of the upper overlapped margin, and the rounding of the antero-inferior angle, giving the complete scale an irregularly ovoid shape. By the splitting of the rock the greater part of each scale shows only the middle layer of its tissue, which is traversed in part by the canal for the lateral line obliquely inclined downwards and backwards ; but there are distinct traces of the rhombic exposed area, smooth and finely punctate. Another broken scale on the same slab shows that the wide overlapped portion is smooth and not impressed by any groove parallel with the edge of the exposed area. An isolated part of a scale (P. 12579) seems to confirm this observation. The quadrangular shape of the exposed area is well seen in a smaller specimen (P. 12581) in grey sandstone represented in Fig. 29. The margins are very slightly and irregularly sinuous.

A transverse section of a scale (P. 12583) under the microscope shows the verniculating chambers in the highly vascular middle layer ; the wedge-shaped pieces traversed by radiating canaliculi forming an upper layer, capped by a thin zone of translucent ganodentine ; and the dense basement-layer with very few vascular canals.

The Osteolepid operculum or cheek-plate (P. 12588) is longer than deep, with its upper portion gently curved inwards. It is much broken, but there are remains of all three layers of its tissue, including the finely punctate shining surface.

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* C. H. Pander, "Die Saurodipterinen, etc., Devon. Syst." (1860), p. 19, Pl. V, fig. 8 ; E. S. Goodrich, n Lankester's "Treatise on Zoology," Part IX (1909), p. 217, fig. 190.

ORDER ACTINOPTERYGII.

Palæoniscid. Figs. 30–34.

A few very small Palæoniscid scales, scattered among the other fish-remains, closely resemble scales from the Upper Devonian of North America, which have been referred provisionally to *Rhadinichthys*.* They are all wider than deep and only slightly ornamented with oblique lines of pittings which sometimes pass into grooves at the margin. All except one (P. 12570) are without the peg-and-socket articulation, and so are probably ventral, dorsal, or caudal scales.

One scale (P. 12589), twice as wide as deep, is produced a little upwards at its antero-superior angle, and seems to show four irregular and unequal serrations at its hinder border (Fig. 30). The pittings on its smooth outer face are few and inconspicuous. A deeper rhombic scale (P. 12563), which also seems to be serrated, has a few superficial pittings tending to fuse into grooves, and apparently a very fine oblique striation of the anterior margin (Fig. 31). An elongated irregularly pentagonal scale (P. 12576), which tapers behind, is ornamented with a few rows of pittings (Fig. 32). Portions of other scales with a similar ornament occur near it.

One imperfect ridge-scale of the tail (P. 12590) is comparatively large, but is marked only by a few minute pittings, and doubtless belongs to the same type of fish (Fig. 33). The two rami of the scale are fused at their pointed upper end, where a row of pits alone divides them.

A fragment of ornamented bone (P. 12591) may also perhaps be the dentary of the same Palæoniscid fish (Fig. 34). At its presumed lower margin there is a narrow smooth area, but above this the whole outer face of the bone is covered with thick ridges of enamel which are nearly parallel, though sometimes branching, and are inclined downwards and backwards from the presumed tooth-bearing border. A dentary thus ornamented is already known in *Rhadinichthys*,† and a nearly similar bone has been found with the remains of the so-called *Rhadinichthys devonicus*.‡

Although the fish-remains now described are so fragmentary that few of them can be definitely named, they are sufficient to prove that the formation in which they were found is of Upper Devonian age. *Bothriolepis* is a common Upper Devonian fossil both in Europe and North America. The Asterolepids with spines and crests seem to have arisen in the Middle Devonian, but *Byssacanthus* is typically Upper Devonian, and *Byssacanthoides* is evidently related to it. The fluted Acanthodian scales from Antarctica provisionally referred to *Cheiracanthus*, may belong to any part of the Devonian series.

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* *Rhadinichthys devonicus*, L. Hussakof and W. L. Bryant, Bull. Buffalo Soc. Nat. Sci., Vol. XII (1918), p. 182, Pls. LIX–LXII, Pl. LXIII, figs. 1, 2, Pl. LXV and text-figs. 60, 61.

† R. H. Traquair, "Ganoid Fishes Brit. Carb. Form.—Palæoniscidæ" (Mon. Pal. Soc., 1909), Pl. XXX, figs. 8, 13.

‡ L. Hussakof and W. L. Bryant, *loc. cit.*, 1918, Pl. LXV, fig. 3.

and so are not distinctive ; but the Selachian dermal tubercles are most closely similar to those of *Cladoselache* from the Upper Devonian (Cleveland Shale) of Ohio, U.S.A. The fragments of a Coccostean and the scales of *Holoptychius* may be either Middle or Upper Devonian, but some of the Osteolepid scales are rather large for a Middle Devonian species and are probably of later date. The Palæoniscid scales, as already remarked, closely resemble some from the Upper Devonian of North America. These are the earliest known remains of Palæoniscidæ, though their wide geographical distribution (in North America and Shetland as well as in Antarctica) suggests that still earlier forms will yet be discovered.

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BRITISH MUSEUM NATURAL HISTORY

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, DUKE STREET, STAMFORD STREET, S.E. 1, AND GREAT WINDMILL STREET, W. 1.

Fish-Remains from the Upper Old Red Sandstone of Granite Harbour, Antarctica.

EXPLANATION OF PLATE.

FIG. 1.—Inner view of keeled Ostracoderm plate, enlarged twice. (P. 12535.) 1A. Polished section to same enlargement.

FIG. 2.—Microscope-section of Ostracoderm plate, enlarged three times. (P. 12537.)

FIG. 3.—*Bothriolepis antarctica*, sp. nov.; right lateral occipital, outer face, enlarged twice. *l.* slime-groove. (P. 12543.)

FIG. 4.—Ditto; left anterior ventro-lateral plate, outer face, enlarged twice. *ar.* articulation for appendage in cross-section. (P. 12545.)

FIG. 5.—Ditto; broken section of articulation for appendage, enlarged three times. *c.* canal in articular prominence; *g.* groove for dorsal articular plate of appendage; *t.* cancellated tissue above articulation. (P. 12546.)

FIG. 6.—Ditto; left posterior ventro-lateral plate, outer face, enlarged one-and-a-half times, with (6A) portion enlarged six times to show texture and ornament. (P. 12547.)

FIG. 7.—Ditto; left ventral articular plate of appendage, imperfect inner face, enlarged twice. (P. 12549.)

FIG. 8.—Ditto; portions of left ventral anconeal (*a*) and external marginal (*m*) plates of appendage, inner face, enlarged three times. (P. 12551.)

FIG. 9.—Ditto; proximal external marginal of distal segment of appendage, showing ornament, enlarged three times. (P. 12552.)

FIG. 10.—*Byssacanthoides debenhami*, gen. & sp. nov.; portion of broken spine, outer view, enlarged three times. (P. 12553.)

FIG. 11.—Ditto; outer view of portion of spine, enlarged nine times, and transverse section of spine, same enlargement. *i.* inner layer; *o.* outer layer; *p.* pulp-cavity; *w.* layer of wedge-shaped plates. (P. 12554.)

FIG. 12.—*Cheiracanthus*, sp.; scale, enlarged twelve times. (P. 12576.)

FIG. 13.—Microscope-section of Acanthodian scale, enlarged thirty times. (P. 12559.)

FIG. 14.—Section of ovoid Selachian dermal tubercle, enlarged six times. (P. 12589.)

FIG. 15.— ,, ,, rhomboid ,, ,, ,, fourteen times. (P. 12561.)

FIG. 16.— ,, ,, ,, ,, ,, ,, twelve times. (P. 12590.)

FIG. 17.—Vertical section of Selachian ,, ,, ,, fifteen times. (P. 12563.)

FIG. 18.— ,, ,, ,, ,, ,, ,, ,, fifteen times. (P. 12561.)

FIG. 19.—Group of Selachian dermal tubercles, chiefly in horizontal section, enlarged six times. (P. 12561.)

FIG. 20.—Outer view of Selachian dermal tubercle, enlarged fifteen times. (P. 12561.)

FIG. 21.—Microscope-section of Selachian dermal tubercle, enlarged fourteen times. (P. 12562.)

FIG. 22.—Ditto. (P. 12562.)

FIG. 23.—Coccostean plate, outer face, enlarged one-and-a-half times, with (23A) ornament enlarged four times. *r.* thickened margin. (P. 12563.)

FIG. 24.—Portion of bend of Coccostean plate, inner view, enlarged three times. (P. 12564.)

FIG. 25.—*Holoptychius antarcticus*, sp. nov.; scale, enlarged twice. (P. 12573.)

FIG. 26.—Ditto; microscope-section of scale, enlarged six times. (P. 12574.)

FIG. 27.—Osteolepid scale, enlarged twice. (P. 12576.)

FIG. 28.—Ditto. (P. 12576.)

FIG. 29.—Ditto, exposed face, enlarged twice. (P. 12581.)

FIG. 30.—Palæoniscid scale, exposed face, enlarged eight times. (P. 12589.)

FIG. 31.— ,, ,, ,, ,, ,, fourteen times. (P. 12563.)

FIG. 32.— ,, ,, ,, ,, ,, eight times. (P. 12576.)

FIG. 33.— ,, caudal ridge-scale, ,, four times. (P. 12590.)

FIG. 34.— ,, dentary, outer face, ,, three times. (P. 12591.)

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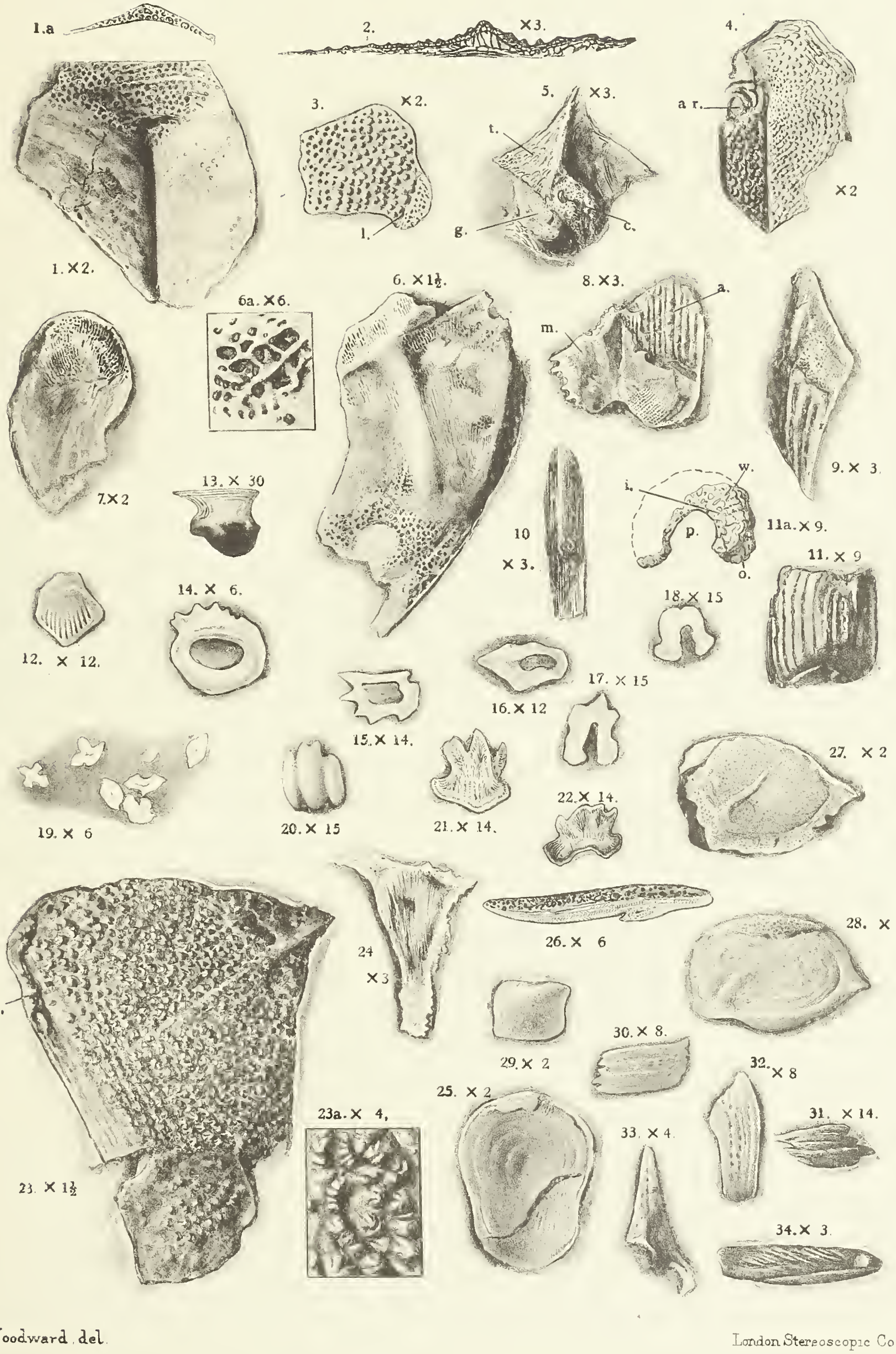

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NATURAL HISTORY REPORT.

GEOLOGY. VOL. I, No. 3. Pp. 63–100.

RECENT AND LOCAL DEPOSITS OF McMURDO SOUND REGION.

BY
F. DEBENHAM, O.B.E., B.A. (Cantab.), B.Sc. (Sydney), F.G.S.
Fellow of Gonville and Caius College, Cambridge.
Geologist on the Expedition.

WITH NINETEEN FIGURES IN THE TEXT.

LONDON:
PRINTED BY ORDER OF THE TRUSTEES OF THE BRITISH MUSEUM.
Sold by Longmans, Green & Co., 39, Paternoster Row, E.C.4; B. Quaritch, Ltd., 11, Grafton Street, New Bond Street, W.1; Dulau & Co., Ltd., 34–36, Margaret Street, Cavendish Square, W.1;
and at the
British Museum (Natural History), Cromwell Road, London, S.W.7.
1921.

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Price Six Shillings.

[*Issued 23rd July*, 1921.]

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INTRODUCTION.

Consideration of the meteorological data furnished by the "Terra Nova" and previous Antarctic expeditions establishes the fact that the conditions in Lat. 78° S. are those of an extreme glacial period such as obtain hardly anywhere else in the world, the important point to be noted being the complete absence of rain which is so universal a factor elsewhere in the production of surface land deposits.

For this reason it has been thought preferable to describe the deposits under the headings of the agencies responsible for them rather than on any regional basis.

The McMurdo Sound region (Maps, Figs. 1, 11) only is discussed here, the other parts of the coast that were visited furnishing less material on account of the few ice-free patches found and the short time available for their investigation. McMurdo Sound is the centre of volcanic activity for that part of the coast, but the deposits due to that cause will be treated under a separate heading in another part of the volume.

The general topography may be gathered from the maps, and is treated in detail in the Physiographical Report of the Expedition.

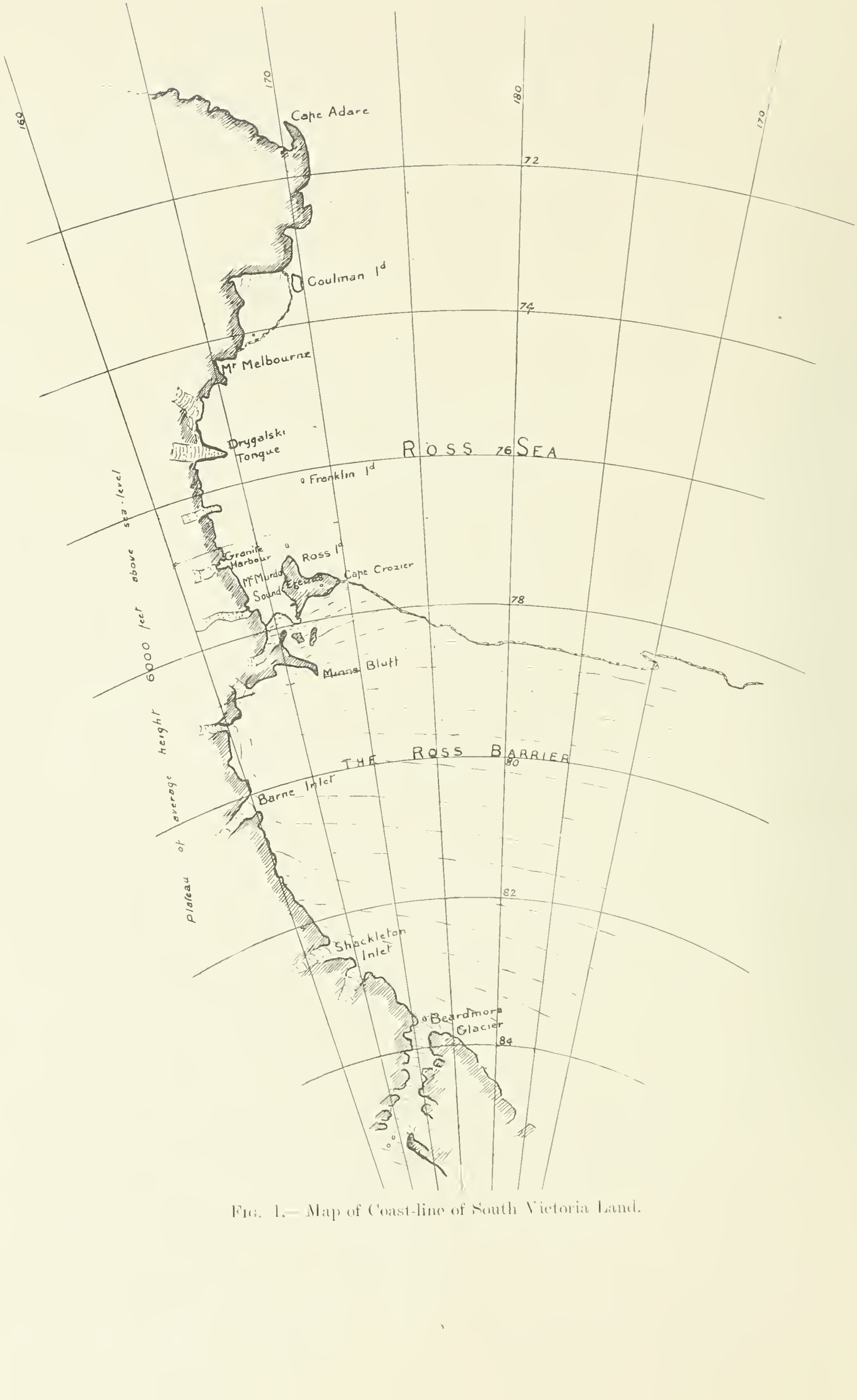

FIG. 1.—Map of Coast-line of South Victoria Land.

DEPOSITS DUE TO THE ACTION OF WIND.

We may preface the description of these deposits with some notes on the observed power of the winds. On the west coast of Ross Island and at Cape Adare, where our two stations were situated, the wind records were far lower than those obtained by the Australasian Expedition in Adelie Land, and therefore cannot be taken as an overstatement of the case for the rest of the continent. At Yarmouth the frequency of winds over 30 miles per hour is 7 per cent. of the total winds ; at Cape Evans, our headquarters, it was 23 per cent. for 1911 and higher for 1912. The mean velocity of the wind throughout 1911 at Cape Evans was 16·7 miles per hour, and in 1912 the mean velocities for the months of June and July were 31·8 and 28·8 miles per hour respectively. But just as in the case of rivers it is the abnormal floods that do the greater part of the geological work, so in the case of winds we are more concerned with the maxima than the means. Gusts of over 80 miles per hour were fairly common in 1912, and the highest recorded by instruments was 104 miles per hour. As the hut was in a sheltered place, and the drifting snow always interfered with the registering apparatus, there can be little doubt that the wind velocity in the gusts reached 120 or 130 miles per hour. The strongest winds of the year being in the winter, we were not able to see the transporting action, but some idea of it may be gathered from the following :—About 120 yards to the S.E. of the hut there was a low gravelly hill, and whenever the wind force rose above 90 miles per hour, the roof of the hut was bombarded by large pebbles from this ridge. The size of the pebbles must have been considerable, for they produced a loud rattle on the roof, easily heard above the roar of the blizzard.

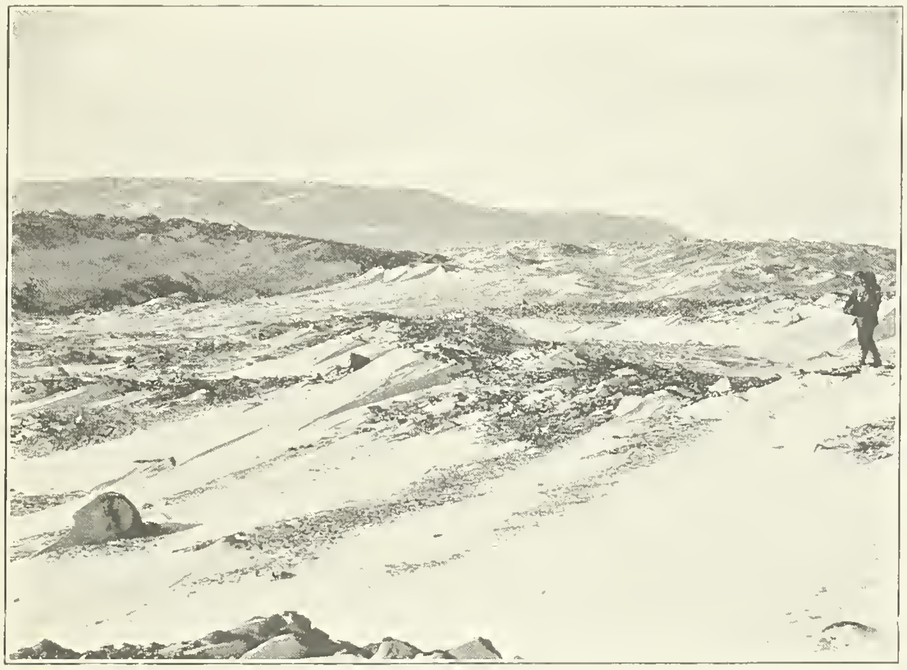

FIG. 2.—Gravel- and snow-drifts on Cape Evans, showing the effect of the prevailing south-east winds.

A piece of English flint was exposed to the wind throughout our stay, and the eroding action of the wind-borne gravel on the surface was noted. On the hard dark fractures it had no more than a polishing effect, but the white selvage was quickly fretted away on the windward side.

Near headquarters, at Cape Evans, the direction of the strong winds was always within a few degrees of S.E., and such a constancy of direction is naturally responsible for the good examples of aeolian deposits that were found. On the lee side of every hill or mound great drifts of snow mixed with rock-dust and gravel would collect, and where for some reason or other the snow was not permanent, the gravel alone was found arranged in exactly the same way as the snow (Fig. 2).

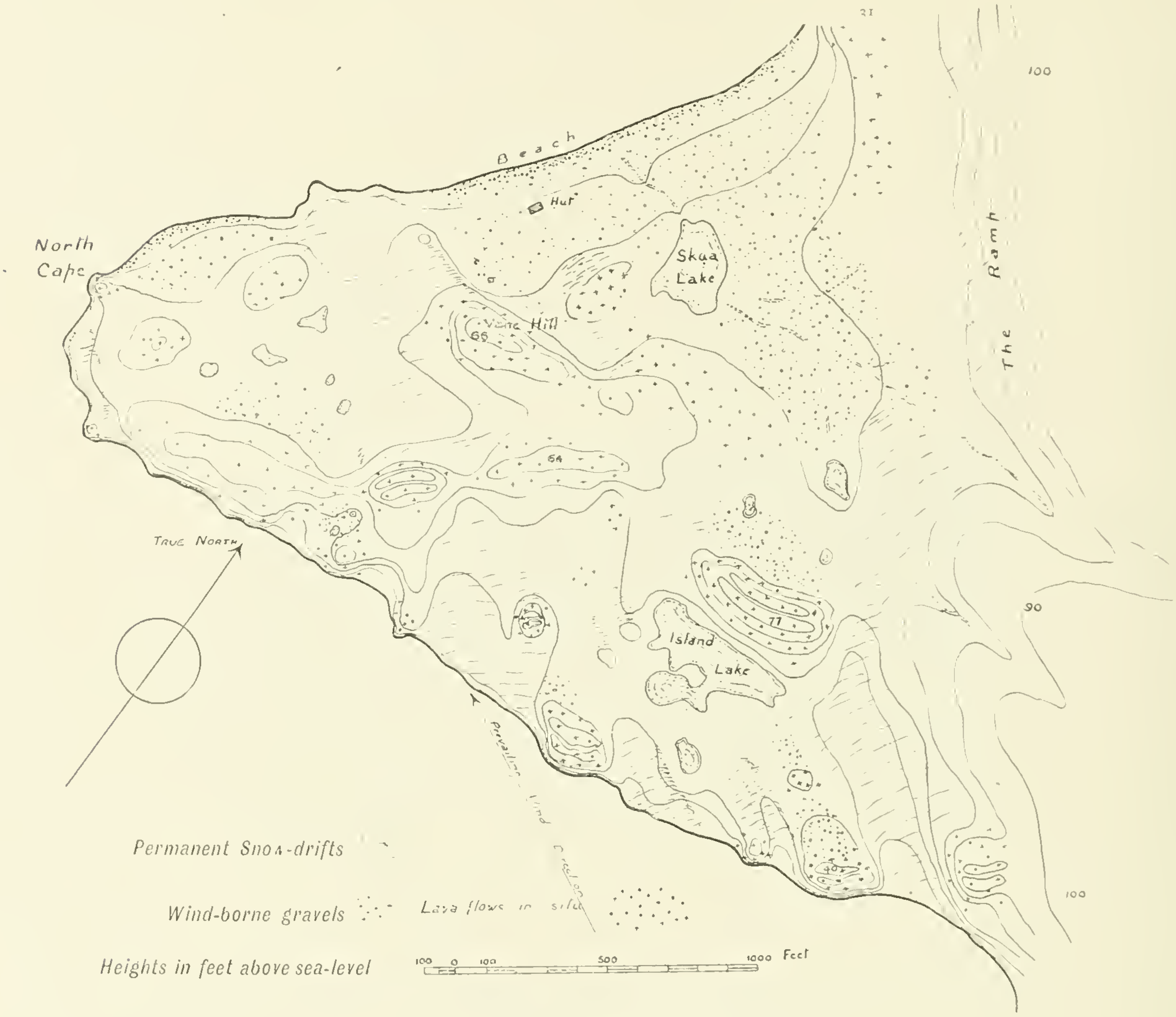

Fig. 3.—Sketch-map of Cape Evans.

Cape Evans (Fig. 3) itself shows a typical example of these local drift deposits. It is a small cape, triangular in section, bare of snow except for local drifts, and under 100 feet in height for the most part. The S.E. side is formed of bare bluffs of coarse lava from which the winds have swept every loose particle, while the N.W. side, only a few hundred yards away, is a gentle slope of gravel, with a few outcrops of rock, leading down to a small definite beach of volcanic gravel. The slopes of gravel were at first taken to be a continuation of the beach, but the shape of the particles and their distribution proved that they were composed of material deposited by the wind as it lost its force in the lee of the south-eastern ridges of the cape. Some of this wind-laid gravel is redistributed by streams of thaw water in the summer, so the next example quoted is taken from a place where neither thaw water nor heavy drifts of snow can obscure the truly aeolian nature of the deposit.

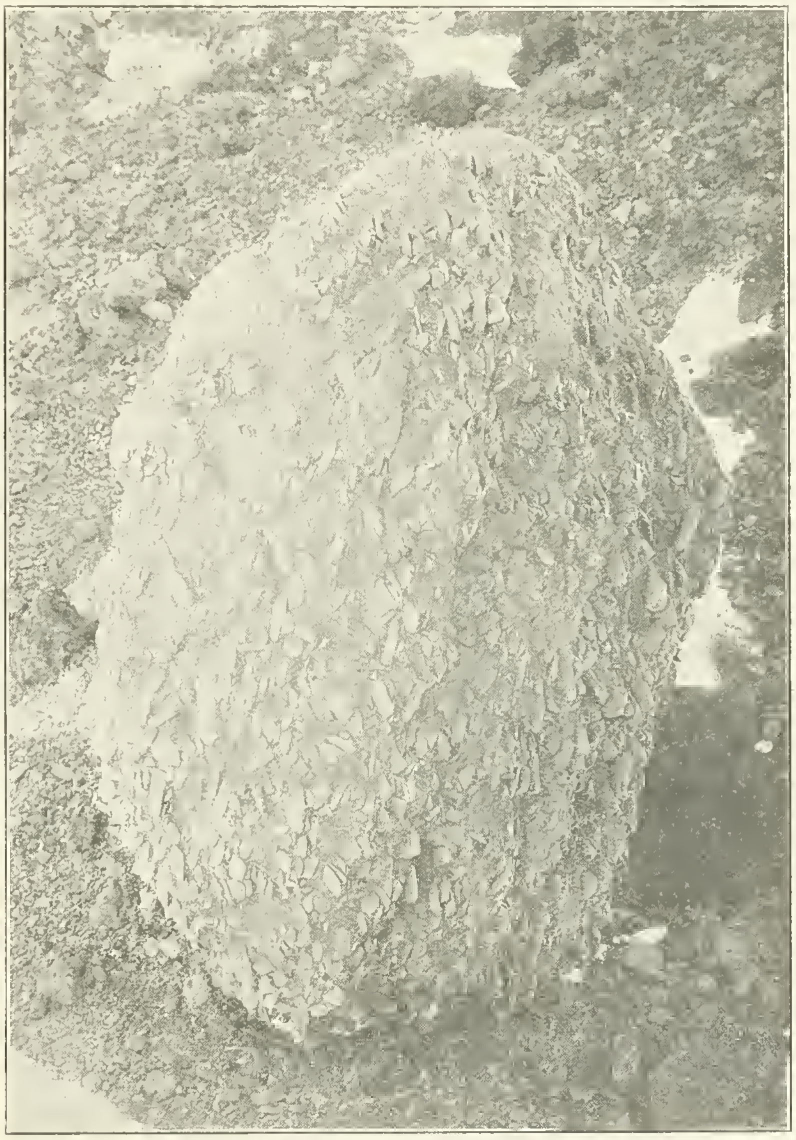

FIG. 4.—Boulder of kenyte, showing the effect of wind erosion; the felspars, being harder than the matrix, stand out in relief.

Inaccessible Island is a high (540 feet) volcanic island about two miles from Cape Evans, and presents a steep face towards the south and a more gradual one towards the north. It is roughly lozenge-shaped and lies obliquely to the direction of the prevalent wind. On account of its high steep face towards the south, there is naturally an area on the north side of the ridge where the wind suddenly loses its force and drops its load. At that height there is very little surface drift snow in the air, and consequently its only load is gravel from the arrêtes and couloirs of the south side. This is dropped in a very remarkable ridge of gravel, coarse at the top and finer below, which runs obliquely along the upper slopes.

The same thing is taking place at Turk's Head, a cape to the south of Cape Evans. At all these places the abrading action of the wind-borne gravel produces peculiar weathered forms. The local lava, being for the most part coarse, with large phenocrysts of felspar, is never worn smooth, but develops a rugged appearance in which the felspar forms the projecting points (Fig. 4), but this and other rocks are sometimes worn into deep potholes or basins (Fig. 5).

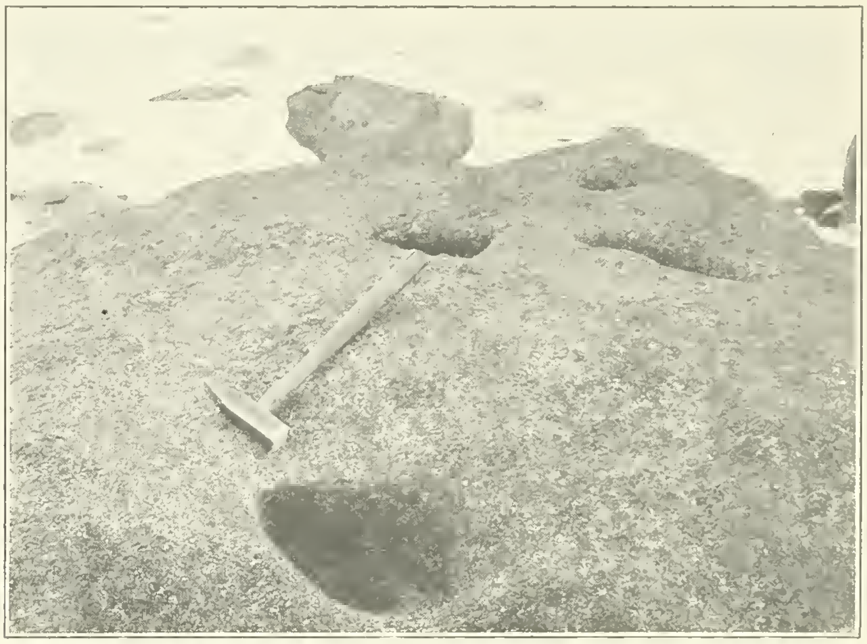

FIG. 5.—Potholes worn by wind action in dense granite. Summit of Redcliffs, Mackay Glacier, Granite Harbour.

Naturally a great part of this blown gravel leaves the land and finds a temporary resting-place on the sea-ice, where towards the middle of summer it forms a dark covering in the lee of capes, greatly accelerating the thaw and ultimately floating off to the north. Since, however, the maximum snow-free surface is exposed to the wind in the autumn when the sea-ice is normally absent, it is obvious that a great deal of the gravel must collect on the sea-bottom in the vicinity of land, and soundings show that such is the case.

Passing across McMurdo Sound to the mainland, generally referred to as the "Western Mountains," we find much larger areas of bare land, and consequently the effect of the winds is much more pronounced. Here, however, the winds are not so constant in direction, and the two blizzard directions are from the south and the west.

Reflected by the high sides of the valleys, the actual direction of wind in any one spot may be altered continually; in fact, in the deeper valleys a strong transverse wind would be transformed into gusts alternately up and down the valley. Such variations have the effect of hiding to some extent the aeolian character of many of the deposits, even though they increase the abrasive action of the wind on the surface.

In the west, therefore, we do not meet with the prominent gravel-drifts in the lee of hills that have been described on Ross Island. On the other hand, the amount of gravel in the beds of the ice-free valleys is far greater than anywhere on the east side of the Sound. The greater part of this gravel is angular and has only reached the bed of the valleys by the agency of the wind, but as it has been mostly re-sorted by thaw water the description of these immense beds is left to the sections on lake- and stream-deposits.

It was pointed out that the rough lavas of Ross Island are never worn smooth by the wind, but the case is quite different on the mainland, where there are many fine-grained dense rocks. In the Dry Valley in particular there are many beautiful examples of small pieces of rock worn into facets by the wind. Some of these showed by their position, firmly embedded in the fine gravel, that the facets were due to the winds that blew alternately up and down the valley, cutting on each side according to their strength.

A striking feature of the wind deposits is that they all consist of moderately coarse gravel, and in no place of any finer material. Any rock-dust formed, owing to the strength of the wind, is either whirled away over the sea or else entrapped in the snow. In the centre line of broad glaciers this rock-dust appears as stratified bands, increasing in frequency from the top to the bottom. It is true wind-borne dust and not "rock-flour" from the bed of the valley, for it can be traced down from the surface to the lower levels, where it seems to accumulate. The muds at the end of these glaciers, therefore, were originally largely due to the action of wind, and not to the eroding action of the under-surface of the glacier.

To sum up the effects of wind in the deposition of material, it is clear that, although the winds are of exceptional frequency and strength, the amount of rock material they can reach is small on account of the few bare surfaces. Consequently, the total amount of material so removed and deposited is probably far less than in more temperate lands. Since, however, the effect of water as an agent of deposition is very small, the percentage effect of wind becomes very large under these conditions.

Still farther south this effect becomes more important, for in the glaciers of 85° S. there is very little thaw indeed, and transport of material can only be effected by the ice itself and the wind. In this region all the glaciers from the plateau reach sea-level, and no permanent land deposits exist. The transported material becomes absorbed in the Great Ross Barrier, and is ultimately dropped by melting icebergs to the sea-floor.

LAKE-DEPOSITS.

As in other glaciated countries there are many small lakes and tarns scattered over the land which is bare of ice. We may classify them shortly into those that are temporary, caused, for instance, by the stoppage of a stream by ice, and those that are sub-permanent. Each class is forming deposits of its own, though usually on a small scale.

The sub-permanent class is particularly well developed in the Cape Royds region of Ross Island, where there is a large expanse of low-lying ground. The lakes themselves generally occupy depressions in the lava flows, though some are due to moraine blocking a natural channel or groove. Professor T. W. E. David and Mr. R. E. Priestley, in an account of these lakes,* show that the only deposits of any importance that are now being formed in them consist of layers of dried algous peat up to three feet in thickness.

This alga, like all the fauna and flora that manage to survive the conditions, is extremely tenacious of life and seems to be the only one at present able to leave a geological record of itself. That it does so there is no doubt, as deposits of it up to one foot in thickness were occasionally found covered by gravelly moraine which, if undisturbed, will eventually preserve it as thin lenticles of peat in a cemented breccia. The most striking deposits of the kind were found by us in the small temporary lakes amongst ice-borne moraine on the western side of the Sound. These lakelets are subject to frequent changes of level, and in many cases were surrounded by small terraces of the dried plant marking the former height of the water. The thaw each year is much more prolonged than on Ross Island, and the plant grows to a greater size, so that we are led to the conclusion that the deposits of this algous peat will increase rapidly with increasing mildness of conditions. The only other type of vegetation that occurs in sufficient quantity to form deposits is moss, but this is local in extent and insignificant in thickness.

Returning to the lakes of Ross Island there is naturally at the bottom of each a deposit of mud, consisting of the fine dust that is blown on to the surface and silt washed into the lake by the small thaw streams. This mud is rarely of appreciable thickness and is so mixed with larger particles of gravel, wind-borne or otherwise, that it can hardly be called a mud in the strict sense.

The lakes of similar character on Cape Evans, as shown on the map (Fig. 3, p. 66), formed quite an appreciable proportion of the cape, though they are all very shallow. These small lakes of the volcanic district provide still another contrast with those of Arctic regions, where the smallest has a steady flow of water into it, bringing considerable amounts of fine silt and mud to form a deposit on the bottom.

On the mainland, on the other hand, we meet with much larger lakes, and as the general meteorological conditions on the coast of the mainland are much milder than on Ross Island, with the increased thaw, even though rain never falls, all the agents of deposition become more active.

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* British Antarctic Expedition, 1907-09, Geol. Report, Vol. I, pp. 229, 278.

The valleys in the foothills of the Western Mountains are not all equally supplied with snow from the ranges behind, and consequently quite a number of them are free from ice. The annual snowfall is so small that it is easily ablated where it falls, and, wherever supply by flow from the plateau fails, the valleys become quite bare during the summer and thinly covered with snow during the winter. These "dry valleys" occur only to the south of New Harbour, the coastal strip to the north of it being occupied with a continuous covering of piedmont glacier. Their very local occurrence is due to the drainage from the plateau being interrupted by the Royal Society Range.

Taking the northernmost valley first, named Dry Valley by Captain Scott on his first expedition, we find a series of lakes from the foot of its shrunken ice-flow, the Taylor Glacier, at intervals all the way to the sea (Fig. 6).

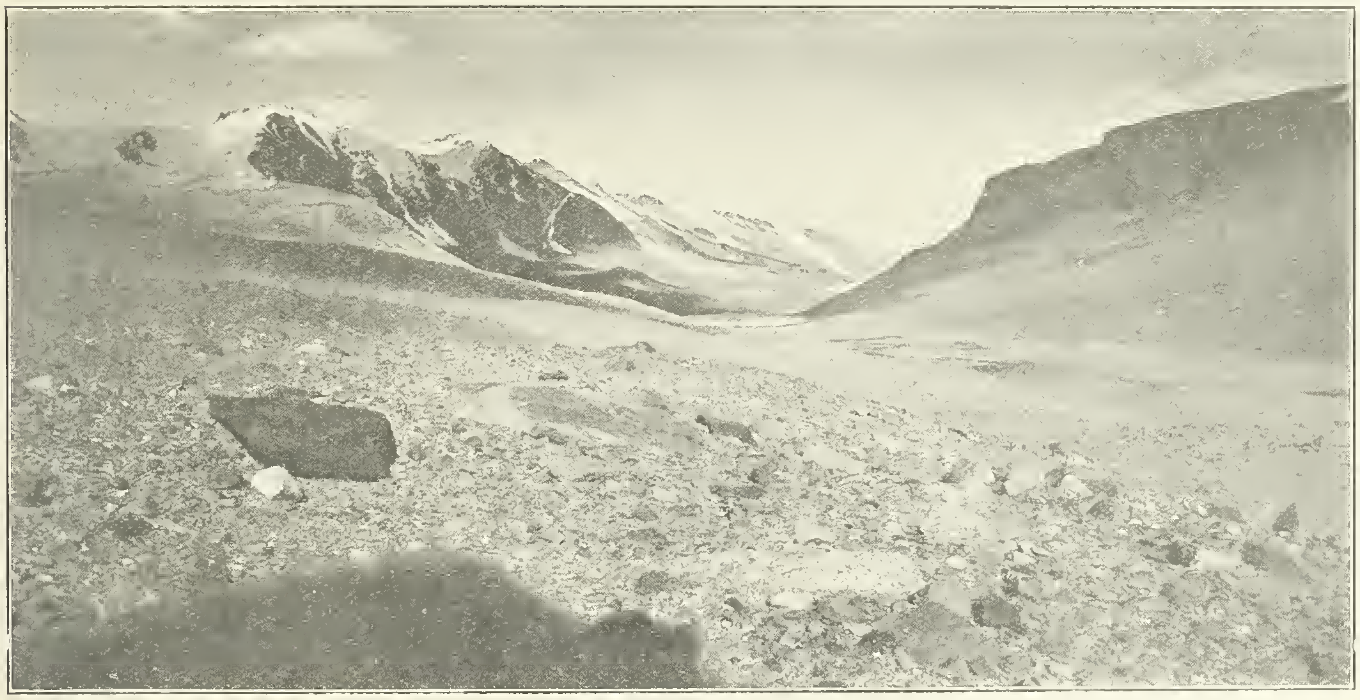

Fig. 6.—Upper part of Dry Valley. Old lake-beds in right foreground. Lake Bonney in middle distance. Recent craters on sides of valley in the distance.

The largest of these is Lake Bonney, which is at present about three miles long and $1\frac{1}{2}$ miles wide, and lies at the upper end of the valley immediately below the snout of the Taylor Glacier. It has obviously been much larger in the past and lies in an area of inland drainage of considerable size. The topography of Dry Valley is remarkable, as can be seen from the sketch-map (Fig. 14. p. 90), and the lake occupies two broad basins linked by a deep gorge.

The whole of Dry Valley is covered with moraine left by the retreating glacier, but in the neighbourhood of Lake Bonney this moraine has undergone a good deal of re-sorting by water. Many streams had cut little V-shaped valleys in it, and the blocks showed some evidence of erosion.

As the lake was frozen when we saw it, we could not determine its depth or the nature of the lake bottom, but in the gorge it must be well over twenty feet in depth. Everywhere there was a considerable amount of the grey-green algous weed we have already noticed on Ross Island, but it was on the outskirts of the present lake that we were best able to judge of the deposits now hidden at its bottom. Like all lakes without an outlet, it is subject to marked changes of level, a fact that was evident in many ways. The most curious of these was that in the centre of the lake was a low platform of ice, much pinnacled and weathered, which represented the level of some former year and had not since been thawed out.

At the sides of the lake the terraced effect to be expected from such alterations of level was not very marked though visible. The former strand lines were represented by lines of dried algae rather than by the usual miniature beaches. The absence of beaches is accounted for by the fact that, in spite of the size of the lake, wave action can rarely be of much importance, as the thaw is usually partial and acts only for a very short period. The lake is shallow at both ends, where the main accession of water takes place from streams. Silting of the lake is taking place here and small deltas are being formed, but there is a general absence of fine mud, the particles of material being all above "dust" size and the water running quite clear everywhere. The reason for this is that, since frost action is the chief disintegrating agent, rock-dust is rarely formed, and the strong winds sweep away what little may be the result of its own action. Beyond the lake to the east, and at a higher level, there are four very definite deposits from former lakes, which give an insight into the types of deposit now being laid down. These were level patches of gravel mixed with finer silt, and were so remarkable on the otherwise irregular surface that they were named "Football Fields." They were connected with each other and with Lake Bonney by stream-channels which had traced small valleys of their own. The farthest field was about 250 feet above the level of the large lake and distant about 3,000 yards. These fields represent old lakes which have been completely silted up or have found a drainage to lower levels which emptied them, the floors being now almost level. The nature of the deposits thus exposed is particularly interesting. One would expect to find the material graded from inlet to outlet, the length of some of the fields being half a mile, but this is not the case. The finer material is everywhere mixed with a considerable amount of coarse gravel the stones of which are sub-angular and sometimes reach the size of a walnut. Moreover, one would hardly expect the whole bed to be of an even level, yet it is definitely so. The reasons for these peculiarities seem to be as follows :—The lakes were probably shallow in any case like the present ones, and were only thawed out for a small part of the year. The normal action of water depositing mud in still water would therefore be taking place only for an inconsiderable period and at long intervals. On the other hand, the action of the wind conveying angular gravel from the sides of the valley would be continuous throughout the year and would spread the gravel more or less equally over the lower parts of the valley. The gravel would be especially entangled in the rough surface of the frozen lake, and, when the thaw came, would melt its way down to the floor of the lake, mixing with the true water-laid silt and obscuring its nature. As could be seen in the sides of the small channels, these lake-deposits do not show the marked bedding that one finds in normal deposits. A definite bedding plane might run for a few feet, but there was little to show that the whole of the material was laid down in water. This appears to be an important observation in its application to the glacial drifts of past times, for it seems that under the conditions named—that is to say, a very short season of thaw—any deposits in basins will be of this hybrid character, a proportion of angular unstratified material with a proportion of finer bedded material. One might almost go so far as to say that the ratio of the one to the other is in direct proportion to the length of the summer, or, in other words, to the time during which the action of streams can produce deposits to cope with the action of wind for the remainder of the year.

Further down the Dry Valley there were other and smaller lakes than Lake Bonney, though of a similar kind. The floor of the valley is everywhere coated with wind-blown gravel which, in the basins, covers the original moraine. The action of the lakes is merely to collect this gravel rather more definitely than elsewhere, and to mix it with a small proportion of finer silt which in places is bedded. It should be noted also that the result of a lake freezing solid as the Antarctic lakes do is to disturb the deposits at the bottom, especially towards the side, and still further obscure what bedding there may have been.

In the large glaciers of the outlet valleys, lakes are frequently found on the upper side of tributaries entering at grade or anywhere at the side of the glacier where the normal flow of the thaw water is obstructed by the ice itself. Some of these lakes are of considerable size, such as the one under the Solitary Rocks on the Taylor Glacier and another to the east of Cathedral Rocks in the Ferrar Glacier. They are peculiar in that they fulfil a double rôle, for in the summer when they are thawed they are definite lakes and receive the lateral streams with their load of material, but when they freeze again they become part of the glacier, sharing in its movement to some extent on the glacier side. The case of such temporary lakes is particularly interesting, as the deposits they collect will remain, when the ice departs, in a most unusual position high up on the shoulder of a valley. One such instance may be described. The Mackay Glacier, in Granite Harbour, passes round several large islands or nunataks which deflect the stream on the upper side. On the lower side is a "backwater" between the reuniting streams, and this depression is always filled by a lake of thaw water. The best instance is that below the nunatak of Mount Suess (see sketch-map, Fig. 16, p. 96). Besides the lateral moraine in this depression, there are long patches of water-borne silt and several small terraces showing the former levels of the lake. At the upper end this lake is sharply marked off from the glacier by an ice slope, almost a wall in places, but at the wedge-shaped lower end it merges into the ice of the glacier so that the junction is invisible.

The small patches of silt and the small terraces in this locality are repeated on a large scale at the mouth of the Davis Valley immediately south of Blue Glacier. The glaciers of the small valleys along this strip of the coast are all far up their respective valleys and have left their moraine on the sides and floor of the valleys just as in the case of Dry Valley, but comparatively recently they were much larger and reached the main Koettlitz Glacier, then a huge stream some fifteen miles wide and

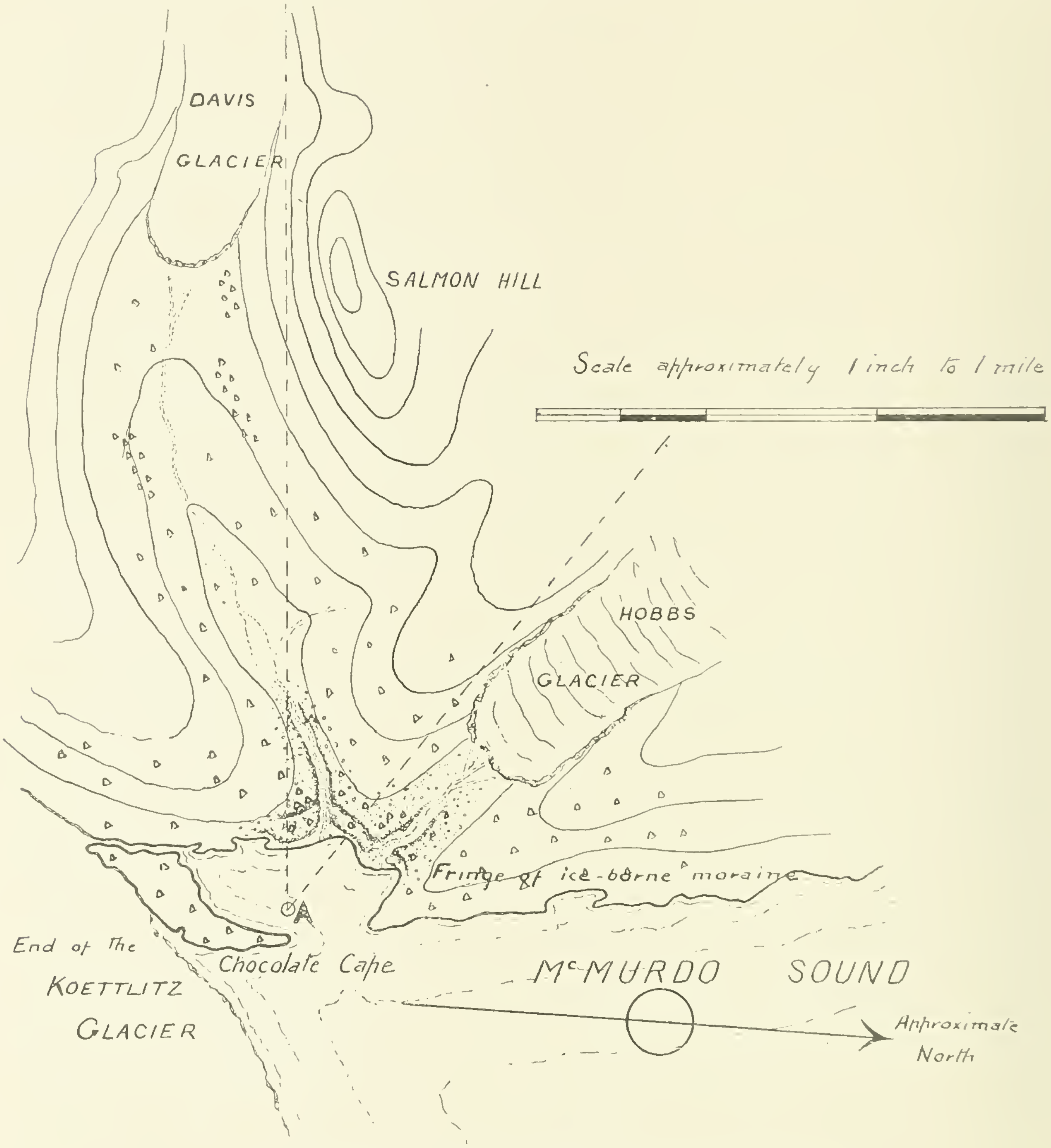

Fig. 7.—Sketch-map of Davis Valley, to show gravel terraces.

some 400 feet higher than it is at present. As the ice began to retreat, the Koettlitz formed an immense bar to the thaw water from these valleys, and large lakes were formed, which, as the ice still retreated, dwindled in size and finally disappeared, leaving their deposits exposed.

An excellent example of this occurs at the mouth of the Davis Valley, and is represented in the map and sketch (Figs. 7 and 8). The terraces here are up to 50 feet in thickness, with level surfaces, and have since been cut through by streams to that depth. At the bottom of the small ravine so formed were large boulders rounded by water action, showing that the short summer thaw can nevertheless account for considerable erosion even in such a severe climate. The material of the terraces is for the most part coarse gravel with a small proportion of the fragments water-worn, but the most striking feature about the whole is the presence of outcrops of the original moraine protruding above the approximately level surface of the gravels. These outcrops are similar to other moraines all along this coast, and show that the gravels were laid down round them as islands.

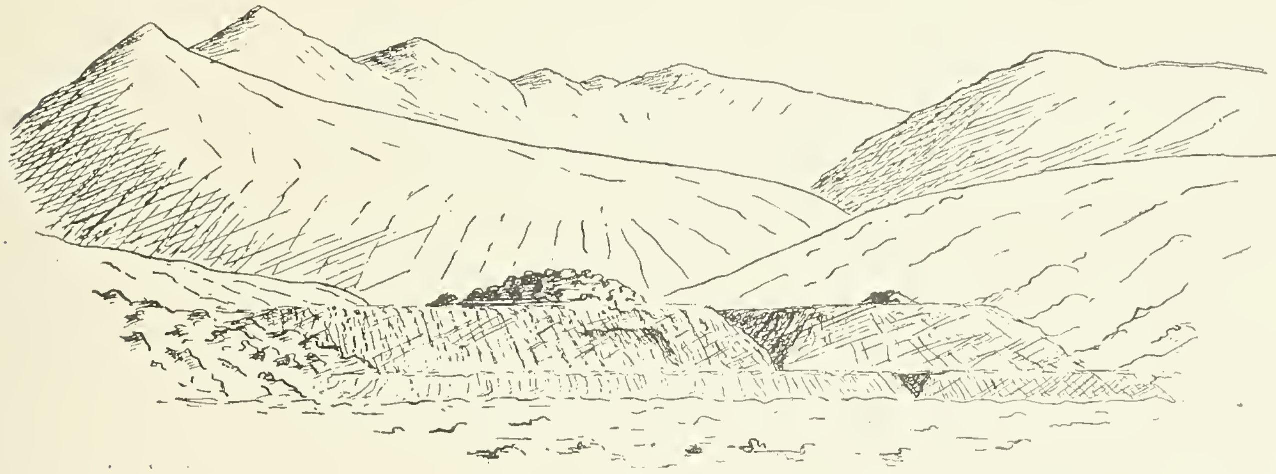

FIG. 8.—Sketch showing old lake-terraces at mouth of Davis Valley. From point A in sketch-map (Fig. 7).

We have here the same kind of processes at work as in the Dry Valley, but on a larger scale, the recent history of the locality being somewhat as follows :—

At some time since the maximum extension of the ice the Davis Glacier had begun to recede from the Koettlitz, leaving the opening of its valley free for the collection of the thaw water from it and its neighbour the Hobbs Glacier, with the result that a large lake was formed against the side of the Koettlitz. The deposits of water-borne silt and wind-borne gravel were then formed over and round the original flooring of coarse moraine. When the main glacier itself receded past the opening of the valley, the lake escaped to the sea, leaving the deposits well above sea-level and arranged in a gradual slope towards it. The streams from the two valley glaciers then proceeded to cut ravines through the loose material, and the much larger stream from the side of the Koettlitz cut back its seaward face. The very definite slope of the terraces as now seen is therefore not due to wave action, which in Antarctic lakes can never be a great factor, but to the transverse washing of a thaw stream. Though terraced in form, they are not lake-terraces in the ordinary sense.

These deposits of silt and gravel are still very loose, and there can be very little binding in the mass for two reasons, firstly, because the proportion of fine material is very small, and, secondly, because there is no water to percolate through it. The snow which falls in the winter disappears in early spring by ablation, and what little water may find its way through the upper surface is permanently frozen a foot or so below.

From the above description it is clear that a section through the whole deposit would expose a most anomalous set of sediments, all the more so since the thaw streams often shift their beds in a lateral direction, leaving the water-worn material to be covered with gravel and moraine falling down the sides of the ravines. The greater part of the section would consist of rudely stratified silts and gravels with only a very slight rounding of the grains. Mixed with this there would be occasional lenticles of water-laid silt and other patches of angular boulders, while through the whole mass would be large mounds of the original moraine. The sequence would be still further obscured by the presence of stream boulders under the unworn gravel, very possibly resting on the original striated pavements of the foundation.

In each of the valleys in this neighbourhood something similar is to be seen, that is to say, there are lake-deposits in the beds of the valleys either on the foundations or on the moraines. The placing of a bar of moraine across these valleys by the Koettlitz Glacier has helped to form these lakes, some of which are of considerable size, as may be seen from the maps.

In summarising the nature and extent of the lake-deposits we must emphasise two main points. The first is that the sediments do not present the usual characters of those of lacustrine origin and would be difficult to recognise as such apart from their original surroundings. The proportion of true mud is so insignificant, the bedding so indefinite, and the sorting of material so little marked, that there is little in common with temperate lake-deposits.

The other important point to be remarked upon is the short geological life of most of these deposits. Situated as they are for the most part in the beds of valleys, it is difficult to see how they can be preserved. Should the glacial conditions continue to moderate, the fluvial action down the valley would quickly transform or remove them; while if the glaciers were to increase again, they would be disturbed and disrupted. The deposits formed by the temporary lakes at the sides of glaciers stand a better chance of being preserved for a considerable period.

The net result should be that after a period of severe glaciation there is no very striking accumulation of lake-deposits, and those that do survive are of a peculiar character.

STREAM-DEPOSITS.

It is somewhat surprising to find that in a region where no rain ever falls the streams can reach such a magnitude as was constantly observed, and if asked for the outstanding feature of Antarctic conditions one would be inclined to say the summer thaw.

On a calm summer day in the vicinity of rocks the thaw is intense, though the air temperature may be hardly above freezing-point. It very soon became obvious to us that the short thaw season was the real geological year on land, and that most of the alterations, whether of erosion or deposition, take place in that brief period of the year.

The true air temperature, as we have seen, is rarely above 32° F., but on calm days close to the ground it may be higher. The most important factor, however, is not the air temperature but the rock temperature, in other words, the heat absorbed by the rocks and passed on to the snow or ice in contact with it. The effects of this action were little short of astonishing, for we frequently observed thaw going on at an air temperature of zero Fahrenheit, and copious streams came from the moraines at air temperatures between 10° and 20° F. Where the moraines are intimately mixed with the ice on which they lie, as in the lower levels of the Ferrar and Koettlitz Glaciers, tiny streams were observed well into March, that is to say, some six weeks after the height of the thaw.

The action may be described as somewhat similar to the warming of the air in a conservatory, for immediately the water came into contact with the air it would be coated with a thin film of ice, which acted as the glass does in letting through the radiant heat and preventing convection of the cold air. One therefore often met with a cliff of silted ice with a skin of thin clear ice on it and thaw water dripping down behind the film and running away under thinly frozen streams at the base of the cliff. The true thaw may take place any time in December and January, and is, of course, subject to complete interruptions by cloudy weather or cold winds.

The following instances will show the order of size of the glacial streams, and it will be seen that they are comparable with those of glaciers in more normal climates, with the limitation that they only run at that rate for a few days, or even hours, in the year.

On the Ferrar Glacier, at a height of 3,000 feet above the sea, a thaw stream was seen in December seven feet in width, averaging nine inches in depth, and running at the rate of 360 feet per minute. Much larger streams than this have been seen on the same glacier, but no exact measurements are available. Nearer sea-level the size of the streams is much increased, and they may even assume the proportions of rivers. It was on the frozen surface of one of these rivers at the side of the Koettlitz Glacier that a party was able to sledge for about 20 miles at the end of February. At this time it was covered with three to six inches of ice, but its former size was easily seen by the limits of the clear ice. At a point 15 miles from its outfall into the sea, the water beneath the ice was at this time 18 inches deep and up to 15 feet in width, but lower down these dimensions were probably far exceeded. It was such a permanent feature that it was named the Alph River (Fig. 9), and its size may be further gauged from the fact that the seals regularly used it as a highway to travel inland as far as 20 miles, so that it must everywhere be well over a foot in depth. An average for the lower portion would be about 20 feet wide by 3 feet deep for the date mentioned, and its rate there was rapid, about 400 feet per minute. Its bed for the whole of its length is the ice of the glacier, so that it is not doing any erosion, but it affords an example of the size of the streams that are possible in the South.

Naturally it is only where the streams descend from the glaciers on to bare ground that any permanent stream-deposits are found, and this takes place in only a few valleys.

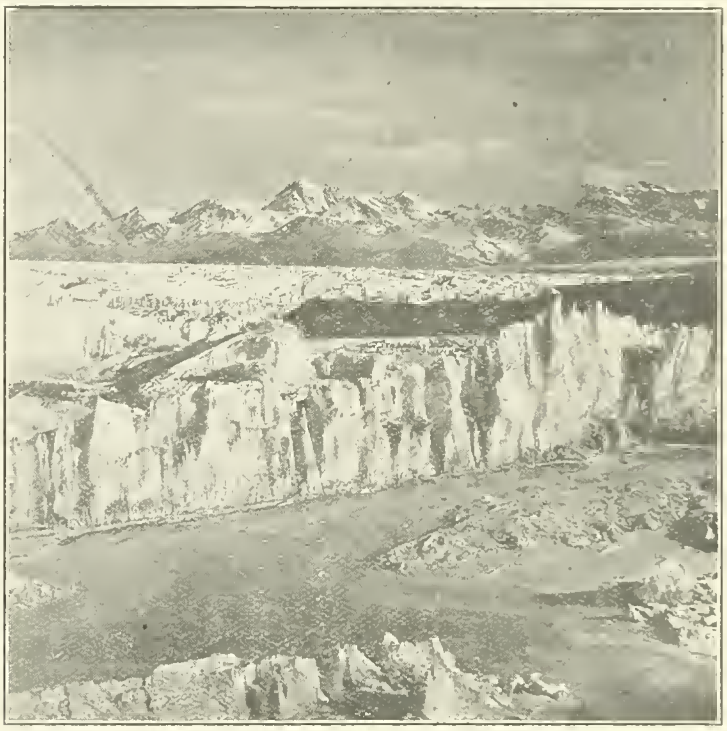

Fig. 9.—Scene on the Koettlitz Glacier, showing results of extreme thaw. Alph River in the foreground. Twenty miles from the sea, but only 100 feet above sea-level.

At the end of the Taylor Glacier in Dry Valley a series of streams run off the ice, and are joined by the streams from the lateral moats before running into Lake Bonney. There is here a large area of 20 to 30 acres of stream-laid silt, flattened in places into the form of a plain, but for the most part uneven and hummocky. The reason for the rough appearance is that, except under special circumstances, the silt is permanently frozen a few inches below the surface, and though originally almost level, in process of time it becomes hummocky through the escape of the ice by ablation or differential thawing. The hexagonal tesselations so typical of water-logged soil which is frozen were particularly well developed in these silt areas, though not confined to them. Small deltas of finer silt were to be found at the edge of the lake.

The important point noted about these silts was their comparative coarseness, the grains being rarely less than the size of ordinary beach sand and often that of a coarse gravel. There was very little true mud, and everywhere the water ran perfectly clear. Washings for heavy minerals were made in the finer silt, and even vigorous stirrings only clouded the water for a moment or two. This fact is of great interest, for it is in contrast with the conditions in other glacier lands. We never came across a stream in the Antarctic that was milky. The point must not be strained too far, however, for all the streams are surface ones, and probably very little of the true ground moraine would be reached by them.

The best instance of stream-deposits that we met with was immediately north of the Davis Valley, already described. Here the Hobbs Glacier comes nearly to sea-level and ends about a mile from the sea itself. The intervening strip was covered with an extraordinarily even deposit of silt, much finer than the terraces of Davis Valley and definitely due to stream action. There were terraces also similar to those in Davis Valley, and indeed the two instances are much alike, except that the grain of the silts was finer in this case, and the wandering stream-beds were so evident that the deposit is classed as a stream-deposit. The tesselations were very well marked, and there is much ice in the silt still. Again the amount of true mud was very small, and the bedding not very pronounced. This is, however, an instance of a more advanced stage of water-laid deposit, and the only one which is truly comparable with those in the Arctic.

RAISED MARINE MUDS AND MIRABILITE DEPOSITS.

A very important series of recent deposits is that of marine muds containing shells of present-day forms. These are found occasionally on the land, but more often on the surface of floating glaciers and ice-sheets. Associated with them are deposits of massive pure mirabilite (sodium sulphate). The origin of these deposits has given rise to much speculation in the past, and has therefore been treated in a special paper* of which only a précis is given here.

The raised marine beds occur in such positions and so perfectly preserved that no pushing action of the ice masses can explain them.

Their general appearance and preservation make it probable that they have risen through the ice. In any ice-sheet where there is decrease by thaw from above and increase by freezing from below, the bottom ice must ultimately reach the surface. If the sheet were occasionally to freeze on the bottom and also to isolate basins of sea water, both shelly muds and sodium sulphate would become entangled in the ice and would ultimately reach the surface.

The numerous instances already found (see Figs. 11 and 12) in South Victoria Land prove that this vertical transport of material by ice is going on over a wide area and with considerable activity. Although most of the effects are not perpetuated, being on floating ice, the few cases where the salts and shells are left high and dry on land provide a problem which is perhaps paralleled by many of the shelly drifts in other parts of the world, and these may be susceptible to a like explanation.

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* F. Debenham. A New Mode of Transportation by Ice: the Raised Marine Muds of South Victoria Land (Antarctica). Quart. Journ. Geol. Soc., 1920, Vol. 75, p. 51.

THE MORAINIC DEPOSITS.

Under the above title are included all deposits connected with ice moving on land, even where water has played a part in their arrangement.

They fall naturally into three groups differing in age and general appearance. The old moraines of the maximum extension of the ice are easily recognised both by their height above present levels and their disposition. The moraines quite recently deposited are distinguished by their own characteristics, not the least marked being the frequent occurrence of old ice still under them. Finally there are the present "active" moraines on moving ice or in the process of deposition. We will consider the last group first of all. It has frequently been stated that there is very little surface moraine on the Antarctic glaciers, and that in this way they differ radically from those of more temperate lands. This appears to be a somewhat dangerous generalisation and needs qualification. It is quite true that the glaciers in the south appear at first sight to be remarkably free from the long lines of moraine so typical of the Swiss and New Zealand glaciers, and none of them have their proximal ends completely hidden by surface moraine. In making a comparison, however, we must be careful to choose similar zones, and on doing so the difference assumes much smaller proportions. Thus the end of a temperate glacier is normally well below the snow-line, where the ice comes under very different conditions of temperature from those obtaining in the Antarctic. If we proceed up such a glacier until we are above the snow-line, the conditions are more similar, and we find that the moraines are quite comparable. In both cases we get the usual curving lines of moraines, with the difference that the temperate glacier moraine contains material of all grades, while the polar one consists chiefly of large blocks, and there is a decided scarcity of gravel or sand on the surface. The actual difference in amount of material is not great, for it varies considerably with the glacier chosen for comparison. For example, in the photograph (Fig. 10) the moraines of the Priestley Glacier are seen to be quite equal in amount to some normal temperate moraines. The real difference, therefore, is with respect to the size of the boulders.

It has already been remarked that the melting of the ice by air-temperature is rare, and the seasonal thaw is almost entirely due to the heat passed on from the rocks to the ice with which they are in contact. The net effect of this action is to bury the smaller blocks. The line of moraine of the Ferrar Glacier, for instance, is marked by a series of large boulders at a considerable distance apart, but a closer examination shows that there are many other boulders half-embedded in the ice, and frequent patches of clear ice show that there are still more a few inches below the surface. These still belong to the supra-glacial moraine, and are not sinking through the ice to the bottom of the glacier.

The sequence of events appears to be somewhat as follows :—When a boulder first appears above the névé in the upper reaches of the glacier, it begins to form a basin for itself by its annual heating effect. As it proceeds down the glacier into warmer levels, this thaw basin increases in size and depth until, if the boulder be only of moderate size, it completely covers the boulder. Under normal conditions the boulder will complete the journey a little below the surface, but variation in the seasons generally causes it sometimes to project above the surface, and at other times to be covered over with snow on top of the thaw ice.

The actual amount of surface moraine on Antarctic glaciers is, therefore, hard to determine, but it is probably little less than that found on glaciers of temperate latitudes under similar conditions of catchment area, etc.

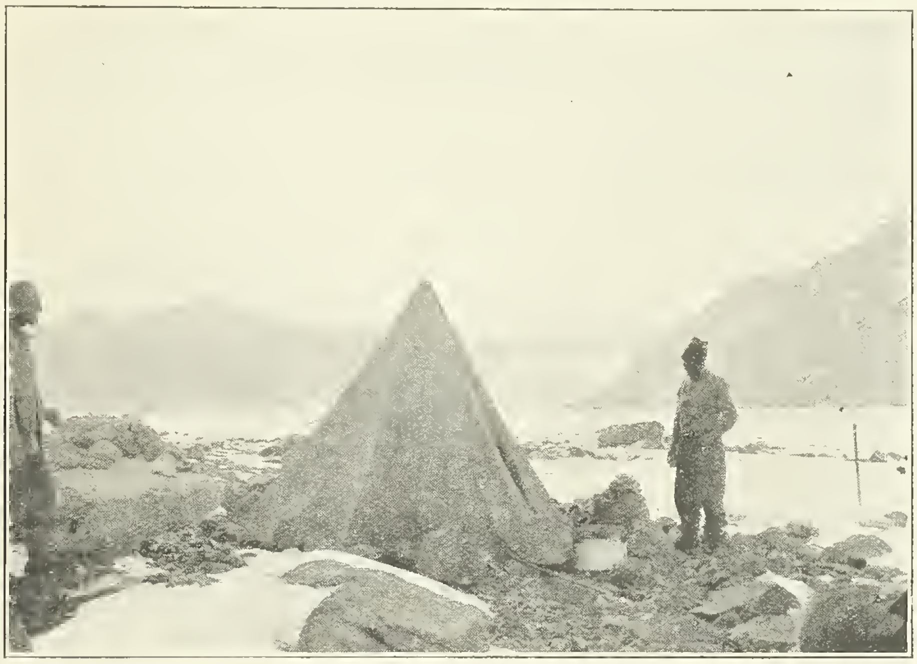


Fig. 10.—Moraine of the Priestley Glacier, lat. 75° S., quite equal in amount to moraines on many glaciers of temperate latitudes.

In the present instance we are more concerned with the deposit of the moraine after it has been brought down to lower levels by the ice.

Here, again, we are apt to infer from the comparatively small amount of deposited moraine that the action of polar glaciers is less than that of glaciers in other parts of the world. The real difference lies in the fact that in the Antarctic there is only a very small amount of bare land on which morainic deposits can collect, and that the greater part of the morainic débris from the land is deposited in the sea. It must again be emphasised that the normal end of a South Victoria Land glacier is at sea-level, and that the few that are found to end on the land itself do so on account of local conditions affecting supply, and their number is comparatively small.

We therefore find but few terminal moraines, and those of a peculiar nature, so that most of our description is limited to the lateral moraines of the main outlet glaciers which have been left on the sides of valleys by the general shrinkage of the ice supply. It will be convenient to deal with them in approximate order of age, beginning with the old high-level moraines, presumably deposited at the maximum of glaciation.

Old High-level Moraines of the Maximum Glaciation.

The most remarkable as well as the best known of these are the deposits found on Ross Island itself. The accompanying sketch-map (Fig. 11) shows the general distribution of these moraines, and it is at once evident that they are referable for the most part to the Ross Barrier and not to local valley glaciers. On Ross Island their study is of particular interest, as the erratics, being nearly all of granites and other continental rocks, are very easily recognised as such against the typical lavas of the island.

Their greatest extension is on the south-east slopes of Mount Terror, where the force of the Barrier expends itself in a glancing direction against the land. The moraine here is piled up in a large terrace, the maximum height of which above sea-level is from 800 to 900 feet.

The curious projection of volcanic rock known as Minna Bluff causes the Barrier to pile itself up in grand folds on the southern side and mount the peninsula to a height of some hundreds of feet, the exact height not being known. The reason for mentioning the fact here is to show that the great height above sea-level at which some of the moraines occur does not mean necessarily that the Barrier was once of that extra thickness. In most of these cases they may have been deposited at that height by the mounting of the ice sheet on to the land. On the northern side of the Bluff, where no such mounting has taken place, the moraines are found only to a moderate height.

On the southern parts of the Hut Point Peninsula, where there is bare rock, a small number of erratics are found. They are all very small and rarely exceed an ounce or two in weight, and consist of the usual collection of granites, granulites, porphyries, and sandstones which characterise moraines from the mainland. They are found chiefly on the high ground north of the Gap, even in the deep crater of Crater Hill the summit of which is 1,100 feet high and has a sharp edge. These have usually been regarded as a moraine from the Barrier at its maximum extension, suggesting that it not only reached a height of over 1,000 feet above sea-level but that the perfect forms of craters were once overridden by the ice, two ideas which seem exceedingly improbable. The uniformly small size of the erratics seems to be evidence of the greatest importance, and obviously it refers the deposits to wind action. They are of a size which could easily be raised and swept for long distances by the strong winds of that area, and the fact that they are particularly common in comparatively sheltered places, such as the bottom of a crater, is additional evidence for the same conclusion. The winds at present being prevalent from a S.E. direction, we may for the moment assume that they came from a large moraine which ran from White Island to the slopes of Mount Terror over an area where there is at present no surface moraine.

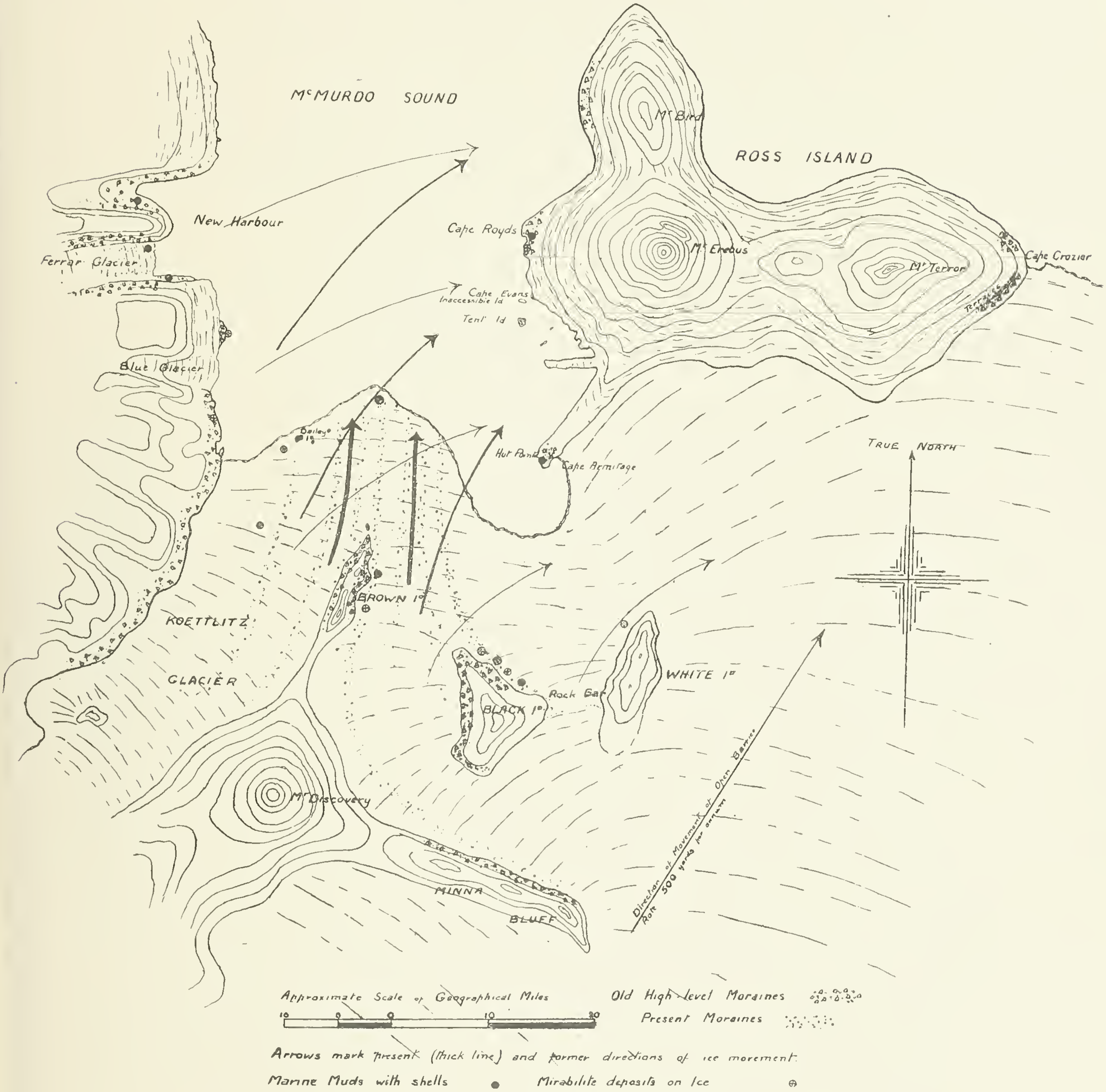


Fig. 11.—Sketch-map of McMurdo Sound region.

Proceeding up the west coast of Ross Island, we meet with a few erratics, some of large size, scattered over the upper surface of Tent Island at heights of 200 to 400 feet.

None have been found on Inaccessible Island which is everywhere steep, nor on Cape Evans which is low, two facts which will be referred to again. On the large extent of bare land in the vicinity of Cape Royds and Cape Barne we find, however, a wealth of morainic material, which supplies the fullest evidence we have of past ice action and has been mapped and studied more carefully than any other part of Ross Island.

The area (Fig. 12) consists of the coastal strip between Horseshoe Bay and Cape Barne, which, unlike most of the coast of Ross Island, has a comparatively low gradient to the sea and is not covered by moving ice. It is due, in fact, to the existence of a number of parasitic cones in the past, the largest of which was at Cape Barne, where the remnant is still well preserved. The whole of this surface is sprinkled more or less thickly with morainic material, which on close inspection proves to be capable of classification into types, and of these it may be possible to infer the approximate origin, and hence the nature and extent of the former glaciation.

It is quite clear that here one glaciation has been superseded by another, and it is necessary, therefore, to classify the moraines less on their rock content than on their mutual disposition.

The most striking feature of the area is the large proportion of *terraced moraine,* which gives a very definite stepped appearance to the topography. It occupies the north and centre of the area, and consists of terraces, cones, and table-mounds of fine morainic material. The terraces are convex towards the lower ground, *i.e.* to the west, and in places are as marked as those already mentioned in Davis Valley. The material is to some extent water-sorted and even rounded, and some of the ridges look very like eskers: at the same time, there is reason to believe that a certain proportion of these gravels are resting on ice still. It consists for the most part of basic volcanic rock with kenytes in moderate quantities and comparatively few mainland rocks.

The direction of the terraces and the recent character of the whole deposit point to the Erebus ice-flows as the chief agent.

There is also a small but very definite moraine which has been deposited on the sides of a small valley to the north of the Cape Barne hills, which includes Terrace Lake. It is entirely composed of kenyte, the typical lava of Erebus itself, and of friable tufaceous muds; the latter show a hexagonal structure due to being frozen while saturated with water. It is obviously due to an overflow of the present Barne Glacier, which, when a hundred feet higher, would be deflected in part into this valley by the coastal basalt hills.

The most interesting of the types of moraine in the area, however, is the one that is almost destroyed by later deposits, the erratics of mainland rocks. These are not deposited in any definite arrangement, as is the case at Cape Crozier, but are found over most of the area; and the rough rule holds that the nearer the sea the larger the blocks. They are reported up to a height of 1,200 feet, but we found none above 900 feet, and those were small. Allowing for the possible action of wind, it seems

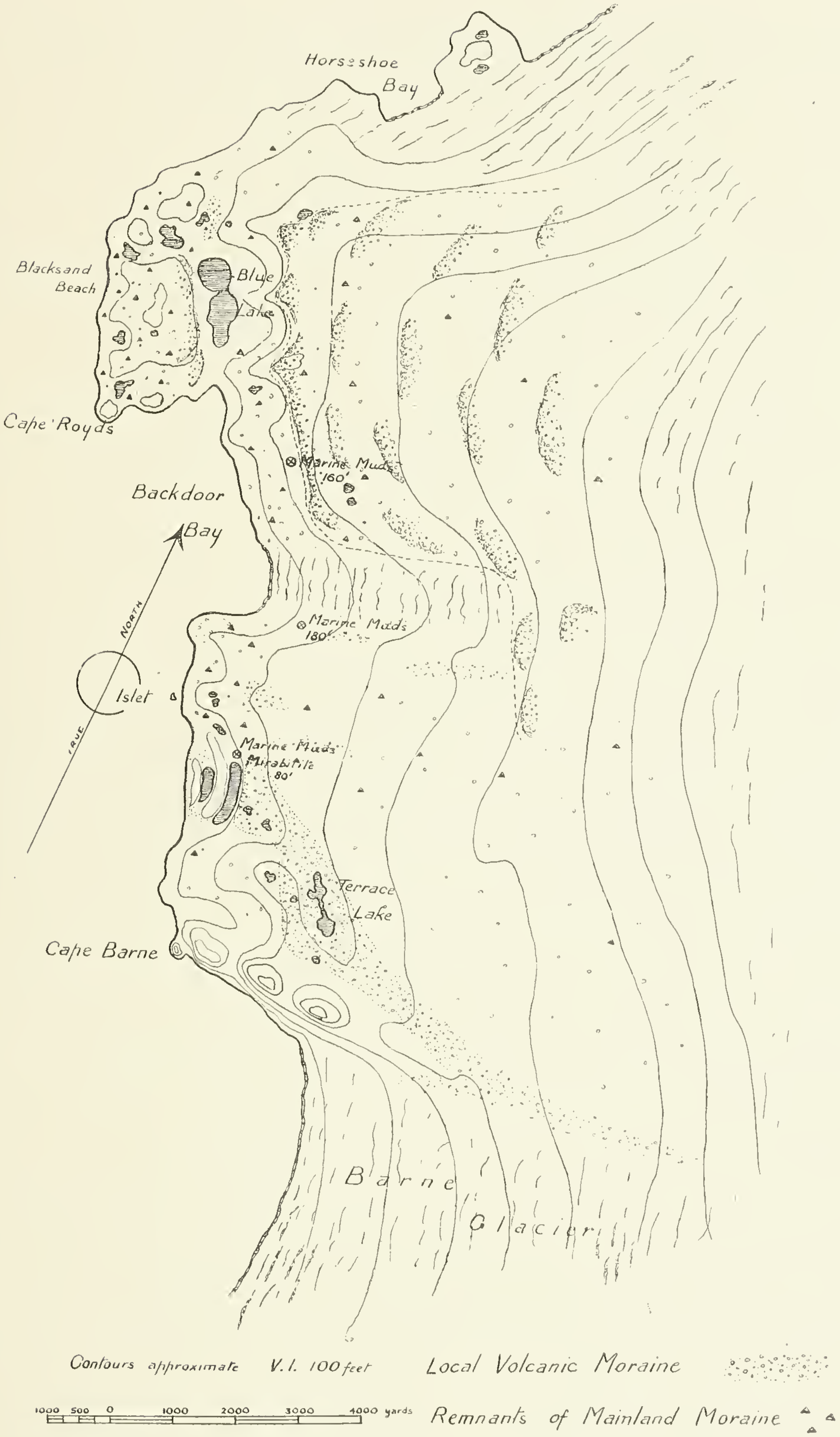


Fig. 12.—Drift Map of Cape Royds.

safer to take the maximum height of erratics of these rocks as in the neighbourhood of 1,000 feet. The types of rock, in descending order of frequency, are as follows :—

Grey Granites,
Pink Granites,
Dolerites,
Schists and Gneisses,
Sandstones,
Crystalline Limestones.

To these might be added basalts near the top of the list, but it is difficult to differentiate between a Ross Island basalt and a dolerite from the mainland in hand specimens. Erratics of similar types are common along the coast of South Victoria Land from Granite Harbour down to the region of the Beardmore Glacier in 84° S. Most of them are rounded, from frost action rather than from water, and many of the granite blocks lie in a bed of their own weathered gravel. No definite inclusions of these erratics were found in the local lava, and they are therefore probably later than the youngest lavas of this area. It is seen, therefore, that there is a sprinkling of mainland rocks over most of the area without very definite arrangement.

These erratics have been hitherto referred to the ice flood of the Barrier, and it has been assumed that to deposit them the Barrier must at one time have been at least 1,000 feet higher above sea-level than it is now. It is true that, if these erratics were deposited as a lateral of the former Barrier extension sweeping up McMurdo Sound, it would be natural to assume that the average surface of the depositing ice was about the height of the moraine, but there appears to be no need to regard it as a lateral.

The difficulty of reconciling an extra thousand feet of ice-sheet above sea-level, that is, a total thickness of something like 5,000 feet, with the other facts of the maximum extension are too great to be ignored, and I take the view that not only was the Barrier not immediately concerned with these moraines, but that another 600 feet only of total thickness of the McMurdo ice-sheet would suffice for the deposition of these erratics.

A glance at the sketch-map (Fig. 11) shows that the present McMurdo ice-sheet is composed of two parts, the western part being derived entirely from the Koettlitz Glacier and the eastern being an overflow from the Barrier, the real direction of motion of which takes it well outside White Island in the direction of Mount Terror.

The two component parts of this sheet have at present an equal value as to rate of motion and supply of ice, for their moraines combine to form a large medial moraine of great width whose direction (thick arrows on the map) is up the middle of the Sound. Let us see what would be the effect of an increased precipitation and supply over the whole area, and let us assume that it be of such dimensions as to bring the surface of the sheet to a height of 150 or 200 feet above the level of the sea, the same height, in fact, as a great deal of the eastern end of the Barrier face is to-day.

We must first examine more carefully the nature of the Barrier overflow into McMurdo Sound. As shown in the map, there is a rocky bar between Black and White Islands, which must come very near sea-level. There is also good reason to suspect similar but lower bars between White and Ross Islands and between Black and Brown Islands.

In any case, it is clear that the only unrestricted course for the present overflow is the sinuous one to the south of Black Island and between that island and Brown Island. If now the surface of the Barrier were 100 feet higher, the overflow, while being greater, would be still restricted by these bars, besides being probably aground between the islands mentioned. Such an increase in supply would, however, have the opposite effect on the Koettlitz and other western glaciers whose course in the Sound itself is barred by nothing more serious than the small group of the Dailey Islands.

The actual course of the ice-flows and of their surface moraines depends on the depths of the sea at the southern end of the Sound, about which little is known. If we suppose in the first place that the overflow from the Barrier would be still of some importance under the postulated conditions, we should get a general direction up the Sound, as shown by the medium arrows on the map. The present nice balance between the two halves of the sheet would be greatly disturbed in favour of the western half, and the moraines would be swept round to the east after leaving the shelter of Brown Island and reach the western coast of Ross Island more or less at right angles. The ice-flows from Ross Island itself would, of course, be increased under such conditions, and the McMurdo sheet would only make direct contact with the land where the local glaciers were thinner and could be deflected or reversed. This would especially be the case on the Cape Royds area and on the present bare land to the west of Mount Bird. The erratics reaching these places would, therefore, be largely composed of rocks from the Royal Society Range, and those found there are certainly common in the foothills of the west. Tent Island and Inaccessible Island would be covered with the sheet, and as it retired would receive a proportion of the moraine. This is definitely so in the former case, but in the latter the steep sides of the island have prevented them from finding lodgment. As the precipitation decreased, the sheet would not only retire, but the general direction of the moraines would swing back towards the centre of the Sound. The reason why there are no western erratics on Cape Evans is because the Barne Glacier itself under such conditions would flow over the low cape and prevent the main ice-sheet reaching it.

If, on the other hand, we suppose that the depth of the sea-floor in the south-east of the Sound is so little that with the increased supply all the overflow from the Barrier would be aground, we should get still another direction of flow, as shown by the thin arrows on the map. The region of Black and White Islands would become a sort of ice-eddy with comparatively little movement and a large amount of surface moraine, while the main mass moved past it to the east of White Island. The western glaciers would then be still less deflected from their natural course across the Sound. This direction of movement would explain the massive terraces of mainland rocks on the slope of Mount Terror and also the wind-borne material on the Hut Point Peninsula, which must have come from a south-east direction under the present wind conditions.

According to the above views, therefore, the erratics of Cape Royds were deposited by an ice-sheet abutting more or less directly on the land, under which conditions it is quite possible for it to mount to a height of 1,000 feet above sea-level, as is now happening at the eastern end of the Ross Barrier. The moraines were probably deposited as a series of rough terraces like those on the slopes of Terror, but as the main sheet retired these would be invaded by the local glaciers and redistributed on the lower slopes. One very definite flow came from the side of Erebus in the direction of Cape Royds itself, and deposited both its own moraine and that gathered from the older moraines in the series of terraces now found there. In the formation of these, water has evidently played a considerable part, but it is not easy to see under what circumstances. Possibly a series of lakes was formed in which the deposits were laid down in the way we have outlined for the terraces of Davis Valley. A certain proportion of the original mainland erratics was left over all the ground formerly covered by the old moraines, the larger ones being for the most part removed to the lower ground.

The last stage in the deposition of moraine on the area is very recent indeed, when the Barne Glacier lodged the kenyte in the little valley to the north of Cape Barne.

It will be of interest to observe what the valley glaciers of the west were doing during this maximum period of glaciation, and the record is particularly clear in the valleys of the Ferrar and Taylor Glaciers.

The sides of both these valleys are clothed up to a certain level with a mixture of talus and old moraine, the limits of which are easily recognisable from a distance. The height to which this old moraine reaches varies a good deal, both with the distance from the plateau, and, what is more important, with the bed of the valley itself. Notwithstanding the higher figures that have been given in the past, I am of the opinion that the moraines are rarely found more than 1,500 feet above the present surface of the ice, and in the valley of the Lower Ferrar they cannot definitely be said to be more than 800 feet above the present glacier surface. The higher figure, 1,500 feet, was obtained from a climb up the side of Dry Valley immediately above the end of the Taylor Glacier. We must be cautious, however, in applying figures to the former extension of the ice over the whole area. In this particular case, for instance, though the glacier did definitely reach to a point 1,500 feet above its present level and nearly 2,000 feet above the bed of the valley, it was because farther down the valley there is a huge barrier to the flow of the glacier, now called Mount Nussbaum, which would cause the ice to pile up behind it. The high-level moraines at a similar position on the sides of the neighbouring Ferrar Valley are not more than 700 or 800 feet above the glacier. Even with these qualifications the height of the old moraines is sufficiently difficult to account for. We have the choice of two explanations—one, that the former precipitation was such that the ice did actually reach a thickness of over 2,000 feet; and the other, that since the highest level of the ice the bed of the valley has been worn down. Without going into the arguments on either side, we may assume that both theories are applicable, with rather less evidence in favour of the heavy erosion of the valley. The height of these old laterals has been cited as additional evidence to prove that the original Barrier surface was about 1,000 feet higher than at present in the Sound and helped to bank up the valley glaciers, but it does not seem necessary to credit the Barrier with such huge proportions.

An interesting discovery was made in the Dry Valley in connection with these high-level moraines. On the shoulders of the valley just below the highest moraines, there are two or three centres of volcanic activity (Figs. 13 and 14), one of which at least was active after the maximum extension of the ice. The existence of a small active crater just above the ice of a large outlet glacier must be somewhat unusual.

Another large series of moraines which requires notice is that which borders the valley of the Koettlitz, and may be called the low-level laterals of that glacier. These are the most extensive of any moraines in the Ross Sea as far as known, covering a stretch of coast at least 30 miles long to an average width of about one mile. They represent the lateral moraines of the former Koettlitz, together with the contributions of the small tributary glaciers on the north side which are now all withdrawn to the upper ends of their respective valleys. The height of the moraines above the present level of the lower glacier is of the order of 400 feet at the northern end, but it is somewhat difficult to decide how much is due to the tributaries and how much to the main flow, so that the height cannot be applied without care to the solution of the former height of the McMurdo sheet.

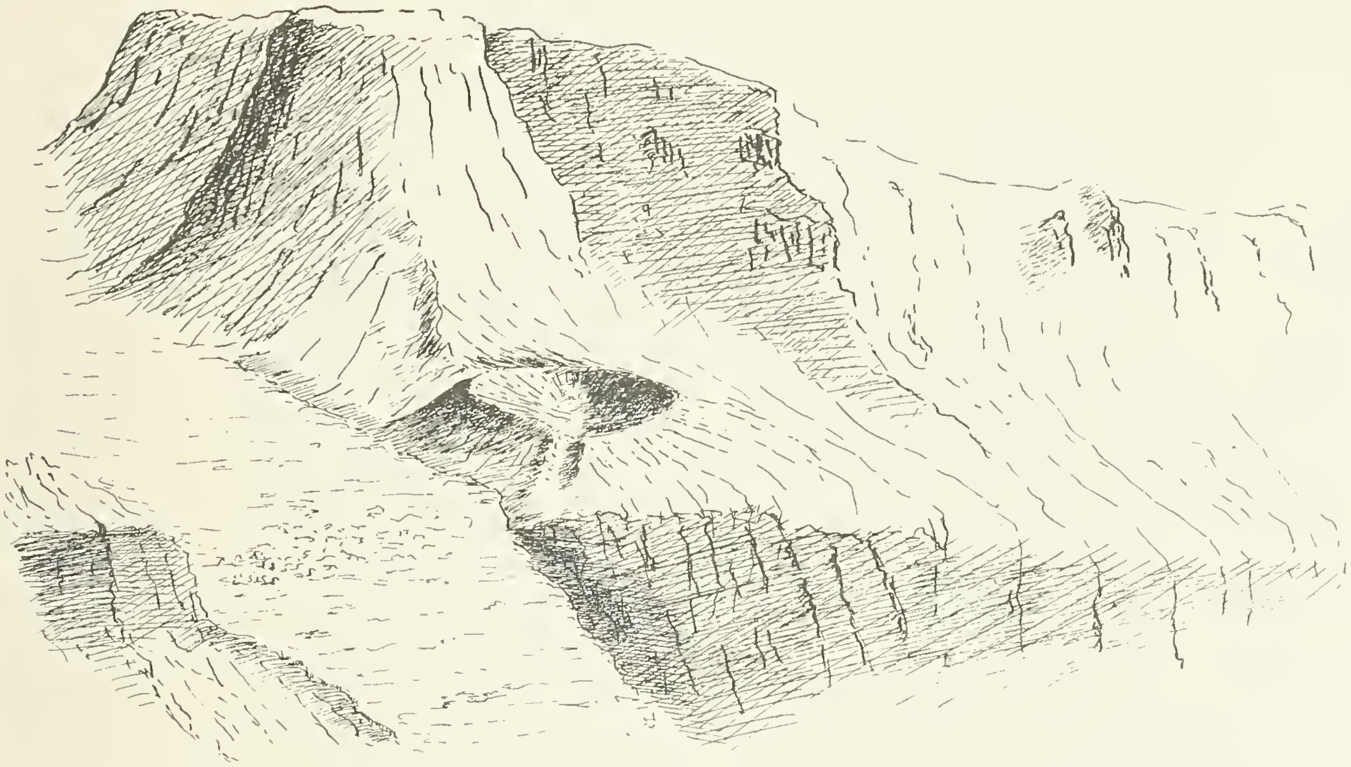


Fig. 13.—Recent crater in high-level moraines of Dry Valley.

The material of the moraines is very diverse, consisting as it does of all the varieties of rock met with on the mainland except the sandstones which were either absent or very rare. This is not remarkable, since the Beacon Sandstone is generally very friable and does not stand transportation over long distances without disintegration. The most constant constituent of the moraines is volcanic rock, chiefly basaltic with a large proportion of olivine, but occasionally blocks of kenyte, the typical lava of Erebus. Kenyte had formerly been found in the neighbourhood of the Ferrar Glacier, and had been cited as evidence of transport from the eastern side of the Sound to the west. The finding of these kenyte blocks in the Koettlitz region disposed of this theory and established the existence of another centre of kenyte lavas in the west.

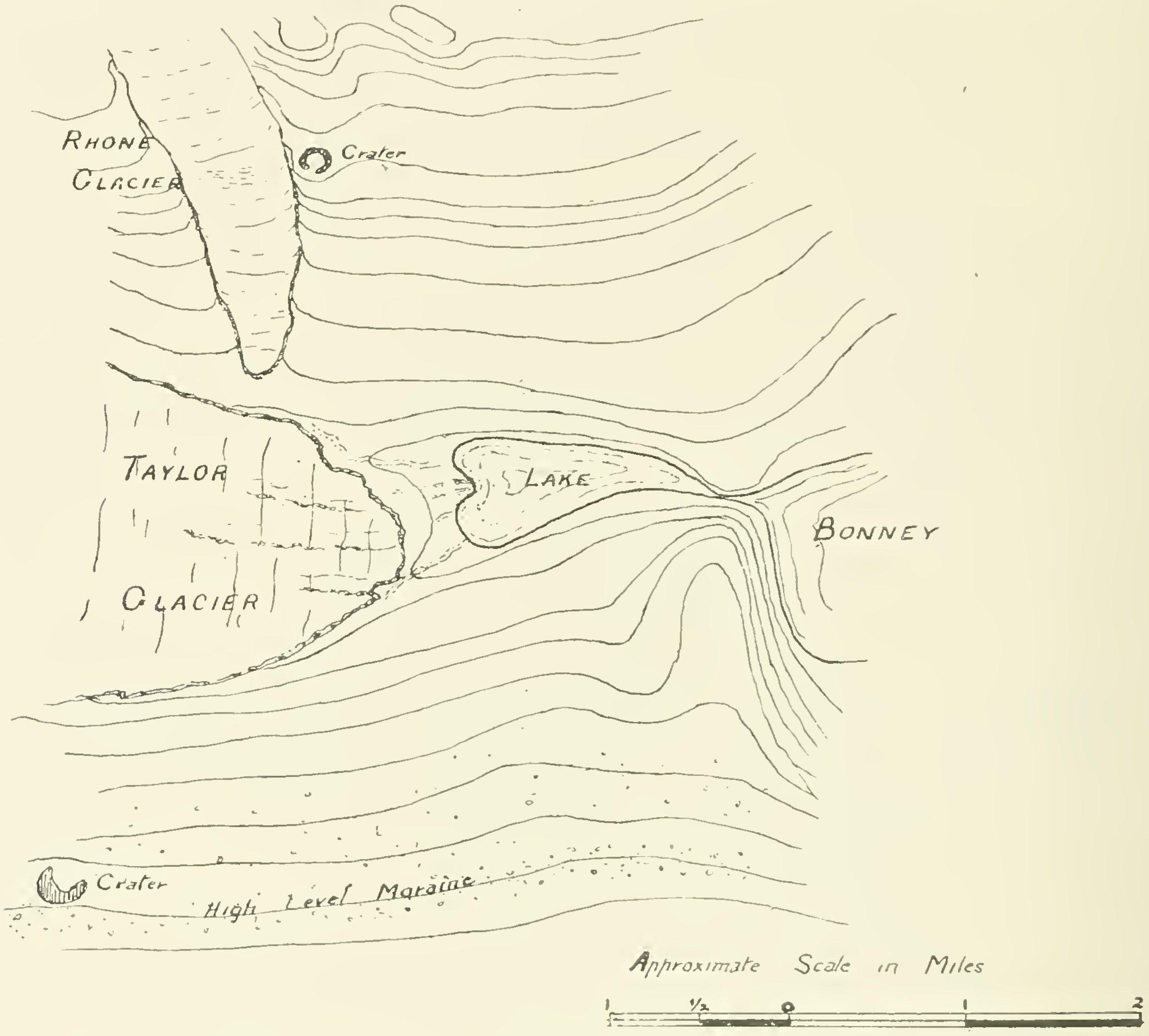


Fig. 14.—Sketch-map of recent craters in Dry Valley.

The most striking feature of these lateral moraines, however, is that a very large part of them is still resting on ice which is protected from superficial thaw by the thickness of the covering. It is, in fact, similar to the lower end of many of the New Zealand and Swiss glaciers, where the ice of the glacier is not seen for perhaps a mile or two from the snout. The difference in the climate and the fact that the Koettlitz ice is not moving are the cause of further differences of an important character, which will be dealt with more fully.

In the first place they are unlike the surface moraines of a temperate glacier in their topography which is somewhat unique and deserves description.

These ice-borne moraines resemble nothing so much as giant relief models, or whole countries in miniature (Fig. 15). It is as if Switzerland, for instance, were dwarfed until Mont Blanc was only 50 feet in height. All the forms of topography are reproduced. Here are inland seas the size of a large room, with rocky islets dotting their surface. Here are winding rivers, complete with watersheds, tributaries, and deltas, emptying into the seas after a course of some hundreds of yards through canyons the height of a man, and over falls the height of a water-butt. They are frozen for fifty weeks in the year, but during their short spell of active life they mimic with perfect fidelity the rivers and lakes of a normal size.

Between the watercourses are mountain ranges, plateaus, and dissected peneplains of every variety, and no better testimony can be given than that the whole system would form a perfectly ideal model on a large scale for lectures on physiography. The commonest feature of all, however, was the existence of innumerable circular lakes, rarely more than ten yards or so in diameter, which displayed miniature terraces on their steep sides, not of water-worn material but of algae which had lived at the edge of the lakelet when it was at that level. All this may be seen for a mile or so without coming upon any evidence of the ice underneath, and, in fact, the miniature scenery was a source of great argument until the solution was found on coming to a small cliff-face of ice.

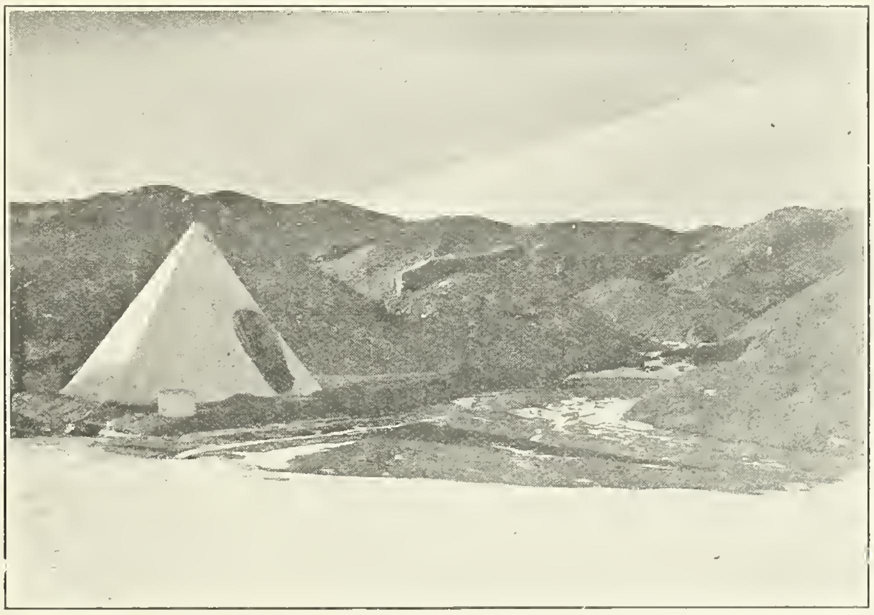


Fig. 15.—Ice-borne moraines stranded on the west coast of McMurdo Sound. Showing the miniature scenery.

The moraine covering the ice is everywhere fairly thick, and for the most part consists of small stones, chiefly black basalt and fine silt, though here and there a larger block would crown a small peak.

The moraine being thick enough to protect the ice from direct thaw, and the ice itself being almost stationary, the formation of this miniature landscape is somewhat as follows :—

Wherever a small stream began, it would eat its way down into the ice in much the same way as stream erosion takes place on land. As the ice itself is full of silt, the thawing is very slow, and may be held up altogether for a while by the fall of loose material into the bed. Wherever the bed is approximately level, the small silt brought down by the stream will be deposited as a miniature river alluvium and will help to preserve the ice underneath, and where the stream reaches a lakelet a delta of the silt is formed. Where there is no outlet for the first stages of thaw in any place, the pool of water collects in any depression and itself continues the thaw. During the winter the surface of the pool loses by ablation, and for the next summer the depression is deeper. The deeper it gets, the more thaw takes place from the heated sides of the basin until, when the latter is some 20 feet deep, the water itself may be as much as 6 or 8 feet deep. The algae take advantage of these warm pools and flourish in the summer. Occasionally the water will escape from a contraction crack forming in the ice, and a sudden change of level will take place, the line of algae remaining to mark the former strand line. Again, where the moraine is so thick that no heat will penetrate through to the ice beneath, no thaw will take place, and a plateau will be formed.

The whole process is perfectly clear when the key to it is provided—that is, the existence of the ice below—and its results are unique.

The moraines are, therefore, stranded on ice, and whatever movement there is appears to be quite local and independent of the remains of the parent glacier which lies to the south and east of the fringe of moraine, generally separated from it by some such large stream as the Alph River mentioned above (p. 78). They are of course gradually shrinking under the process, and the final result will be a fringe of what would be called normal moraine with a high proportion of silt, except for two contrasted deposits which a careful search would reveal. These deposits are, firstly, the layers of algae which in places may reach a thickness of a foot ; and, secondly, the occurrence of sodium sulphate and recent marine shells (page 79). These two were found by us in actual juxtaposition, and at the time were completely beyond our explanation.

It is easy to see that under warmer conditions, such as in the Arctic regions, where there is an abundance of forms of life, such a moraine might include even thick peat deposits with fossil bones long before the ice had completely disappeared from beneath the deposit.

The proportion of ice under the surface increases as one ascends the glacier, if one can speak of ascent when the actual rise is only about 100 feet in 20 miles, and opposite Heald Island the ice-borne moraine is seamed with really large stream-channels and gorges. Here the walls of ice are easily seen, and the water has cut for itself long tunnels through the ice as in any temperate glacier.

The ice-borne and the true moraine cannot be easily distinguished, but I am inclined to think that the former may in places reach the height of 80 or 100 feet above the present level of the glacier. Beyond that, the more normal moraine covers the slopes of the broad valley sides up to a height of 400 feet or so, and much more near the mouths of the tributary valleys.

Terminal Moraines.

In a terminal moraine one generally expects to see a huge rampart of mixed rocks lying athwart a valley, as in the case of the Alpine glaciers. This form of terminal is never met with in the Antarctic, and its absence requires some explanation. Although in the tributary valleys of the Koettlitz Glacier there are huge bars across the mouth, these are definitely due to the lateral deposit of the main glacier and not to the terminal deposit of the tributary. In every case where a glacier has been retreating up its valley, as in these cases or in the case of Dry Valley, the deposit of moraine has been gradual, and the bed of the valley is more or less evenly coated with the débris. The same thing also occurs at Cape Bernacchi, where the Wilson Piedmont Glacier has already retreated some miles.

Not only are there no ancient terminal moraines, but there are no present-day ones worthy of the name. Every glacier that ends on land ends in a sheer face and has below it merely silts and muds washed off the glacier, together with a small proportion of boulders. Yet, as shown above, there is ample surface moraine of large erratics to form respectable terminal moraines, and the question is what becomes of these, or, rather, why do they not collect at the end? The answer to the problem appears to lie in the small differential movement of these glaciers.

In a normal temperate glacier the rate of movement of different parts of the glacier may vary enormously. It may, for instance, have a high rate of movement at the middle of its course and yet be stationary or retreating at its end. The reason for the apparent anomaly is, of course, the great change in temperature conditions along its course, and the effect is to pile up all the material at the lower end and form the gigantic ramparts that are so common in the Alps and elsewhere. In the Antarctic, however, and almost equally so in the Arctic, the change in temperature conditions along the course of a glacier is not very marked and may be so little as to be negligible. (It must be remembered that the temperature change which is of extreme importance is what may be called the thaw-point—that is, the condition under which thawing from air temperature takes place—and this is rarely reached in the Antarctic.) The result is that there is very little differentiation of rate of movement in the glaciers.

Putting the matter in another way, two boulders that fall on the névé of a temperate glacier 100 yards apart will decrease this distance on the journey down the glacier, and may be together at the end. In an Antarctic glacier, on the other hand, they will remain at 100 yards distance, or nearly so, all the way.

The question then follows as to what is happening at the end of these glaciers, since the loss by thaw is so inappreciable ; why do they disappear at all, and how do they get rid of material? The answer is that, as stated above, the normal end for an Antarctic glacier is in the sea where it breaks off periodically, and the material is never collected together. When abnormal conditions supervene, such as a shrinkage of supply, so that the glacier can no longer reach the sea, it does not mean so much that it has not time to reach the sea before melting, as that the supply, coupled with the very slow motion, is gradually ceasing. It gradually disappears by thaw, as in the case of the Dry Valley Glacier, but very slowly and evenly, and there is still too little differential movement to collect the moraine together appreciably.

The absence of piled-up terminal moraines is therefore due, I think, almost entirely to the temperature conditions, which affect the differential movement and tend to prevent the accumulation of material anywhere on the glacier itself. A contributing cause is the slowness of the motion and the continuous and even retreat of any glacier whose supply is failing.

Whatever explanation be accepted, the undoubted fact of their absence is a point of considerable importance and leads us to the conclusion that, where the snow-line is truly at sea-level, glaciers will normally reach the sea, and there will, in any case, be no large terminal moraines.

While on the subject of moraines, it will be convenient to include some remarks on striated boulders and rock platforms, since it is by these that many moraines are recognised as such in temperate countries.

The scarcity, in fact almost complete absence, of striated boulders in the moraines of the Antarctic has been noted by several former geologists, and needs explanation, for it is apt to be taken as direct evidence of a small amount of ice erosion.

In the course of the examination of many miles of moraine, we found only a few specimens of striated boulders or small stones, certainly not more than fifty good cases, whereas on the terminal moraines of many temperate glaciers they may be picked up every few yards. This is a very striking contrast, but it appears to be capable of a perfectly normal explanation.

In the first place, there are very few true terminal moraines in the Antarctic, and consequently few boulders which have been in the ground moraine of a glacier. By far the greater majority of moraines are composed of rocks which have never been below the surface of the carrying glacier. The true ground moraine, which undoubtedly exists in the glaciers, is carried to its proper termination, the sea, in all cases except the comparatively few where the glacier now ends on land, and in these cases the motion and consequent ability to erode is deficient. We should, therefore, seek for striated boulders on the sea-floor rather than on the land, and such a search is rewarded. In the dredgings which have brought up a number of rocks in Ross Sea there is often a striated boulder, and the proportion is far higher than is ever found on land.

Another reason for the rarity of striated boulders on land is the rapid weathering of the rocks by sub-aerial agents, notably wind and frost. This has been pointed out by Professor David for the Cape Royds area, where striations are never seen on the upper surface of rocks, but an occasional example may be found by examining the under surface where it has been protected from the air.

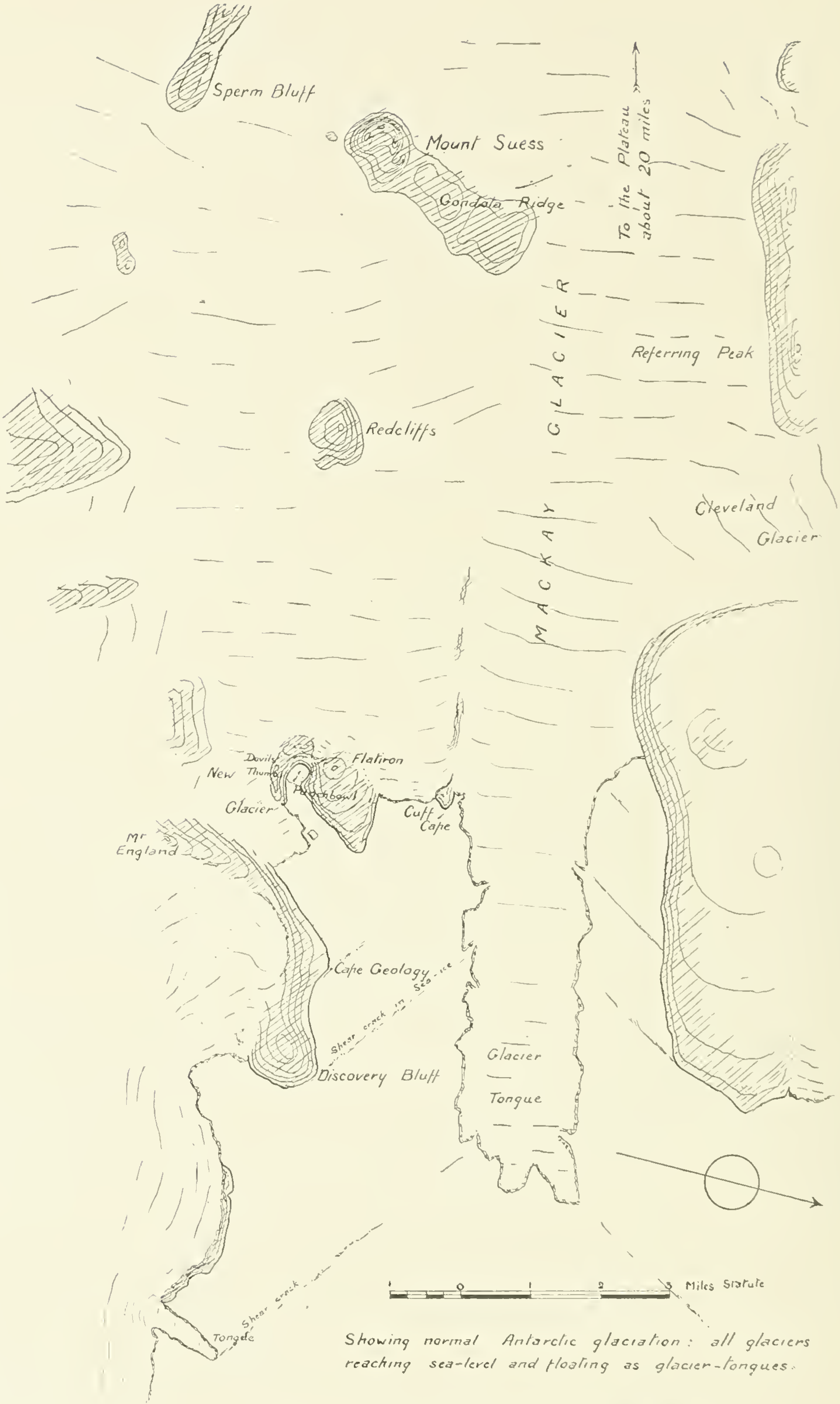
If there is a normal amount of sub-glacial erosion taking place in the South, and one product of it, striated erratics, is lost to view in the sea, we should be able to find the other product, striated platforms, in fair proportions, and this is so. On account of the rapid effect of the sub-aerial weathering, we do not find very clear striations on rocks that have been for a long period uncovered by the ice, though the general effects of erosion, the "roche moutonnée" form, remain distinct. These are very definite along the coast, where not hidden by lateral moraine, and on a large scale are best seen in the Dry Valley, where the massive bars of rock present a very rounded aspect and the curve of the valley-bed is characteristic.

Where the surface of the rock has but recently been uncovered by the ice-stream, however, striated platforms are found in great profusion. The best examples were found on the Mackay Glacier in Granite Harbour, and a short description of them may be of interest.

The map (Fig. 16) shows that this glacier meets many obstructions which it has either surmounted or passed round, and most of these show the recent gradual retirement of the ice, or rather the decrease in supply. Taking two cases at sea-level first, the points which have been named Cuff Cape and the Devil's Punchbowl, it will be observed that in each case the ice-flow has obviously only recently ceased to pass right over the rock. At Cuff Cape, in fact, it is still fringing the upper portion of the small cape like a white cuff on a dark hand, and the rocks bear witness to its recent retreat. The Cape is formed of coarse granite intersected by numerous small dark basic dykes, and the former, being more susceptible to frost weathering, shows the rounded forms only, except close under the present front of the ice where the striations are clear. The dyke rock, being very hard and fine-grained, has all over the Cape retained striae. There were also several striated erratics on the Cape, as one would expect, for the ground moraine of a glacier in full action is here intercepted and dropped.

The Punchbowl, at the south side of the Harbour, is a most interesting place for many reasons, and shows by its form alone how recently it was covered by the glacier. Striated platforms of rock were to be found all along the narrow ridge on the southern side as well as on the summit of the Thumb, which is now 250 feet above the glacier. As on Cuff Cape, the best striae are found on the fine-grained dyke rocks.

Some six or seven miles up the glacier from the sea there is a large nunatak named Mount Suess by Professor David, and on the northern end of this outcrop the rock is comparatively low and has only been recently uncovered by the ice. The gradient of the ice-flow is very steep here, and all the conditions for erosion are present, so that we find ample evidence of its effect. All over the low promontory were striated pavements of the red and grey granite that is the chief rock, and piled over them were numerous



Showing normal Antarctic glaciation: all glaciers reaching sea-level and floating as glacier-tongues.

Fig. 16.—Sketch-map of part of Granite Harbour.

erratics, many of them perched in the most insecure and transitory positions (Fig. 17). A considerable proportion of them were themselves striated, and specimens of perfect parallel striae were to be found at every step in both the coarse and fine varieties of rock.

To sum up on the subject of striations, it should be clear now that the rarity of striated stones and boulders is natural under the circumstances, and that it cannot in any way be used as an argument against effective erosion. When looked for in the proper places they are as abundant as in any other glaciated region, but in the valleys south of the Ferrar Glacier, which contain stagnant ice only, they are reduced to a minimum, the products of erosion here having been distributed in the sea when the glaciers were active and reached their proper level.

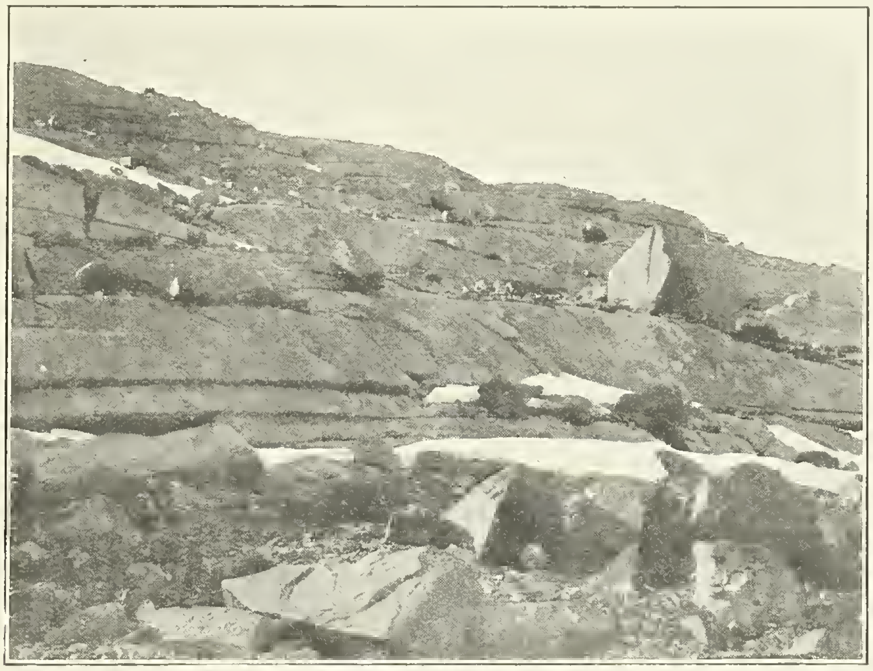


FIG. 17.—Stepped structure of the granite of Gondola Ridge, Granite Harbour, showing the effect of a recent covering of moving ice which has deposited the erratics.

BOULDER CLAY.

Just as the rarity of striated boulders in the South is at first sight a great surprise, so is the almost complete absence of boulder clay on land, for those two in other regions are the chief marks left of an ice age ; but again a little consideration shows that this absence is only natural at the present stage of glaciation.

It is clear that the material which forms the till or boulder clay is that which is included in the ice chiefly towards the base. Whether it consists of "rock-flour" or of wind-borne particles does not concern us now. In many places the sheer walls of glaciers can be seen, and almost invariably the lower part of the ice is filled with fine material which is arranged in fine bands (Fig. 18). This material is so thick towards the base that it is often impossible to say where the ice ends and the floor of the valley begins. In these respects the Antarctic glaciers are precisely similar to those of North Greenland and Spitsbergen.

Together with the fine material is a certain proportion of coarse gravel and an occasional larger block. We must pay some attention to the finer material in order to understand the absence of real clays, and we find that very little of it can be considered as smaller than fine sand, and it may be called a silt rather than a mud. Naturally this material when deposited in mass will form a till without the clay. To understand this, we must refer to the nature of the rocks of South Victoria Land. As we have said before, there are no recent sedimentaries, and what there are consist for the most part of sandstones. In the sandstone there are a few thin bands of shale of insignificant proportions. The remainder of the rocks consist of a very hard dolerite, coarse granites, and a series of metamorphic rocks. There is, therefore, no rock in the vicinity that will form a clay except by excessive trituration, which is a slow process. It seems probable, therefore, that not only are the silts of these basal moraines free from much very fine material on account of the nature of the rocks over which they pass, but further, that most of the very tough boulder clays which have been formed on land in other regions are due to the presence of soft sedimentaries in the district which require very little breaking up to form a clay.

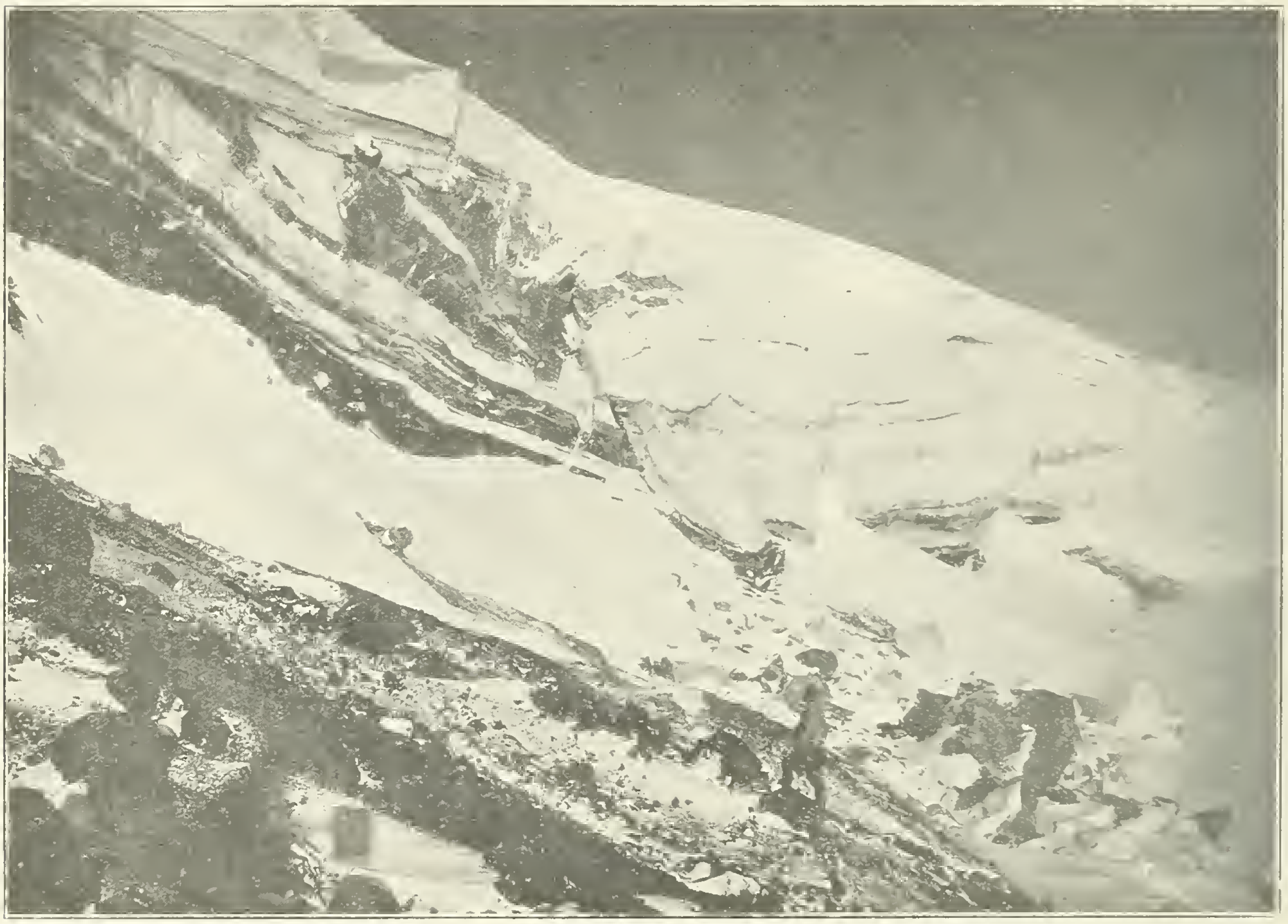


Fig. 18.—Terminal face of Barne Glacier, Ross Island, showing bands of silt.

The case is a little different on Ross Island for this reason. Amongst the rocks that clothe the sides of the volcanic cones are a number of very fine and soft tuffs, and accordingly we find that the material at the base of glaciers such as the Barne Glacier is very fine indeed, and would, when deposited, form a clay (Fig. 19).

In the few places where it is possible to see this basal moraine deposited in mass, as in Dry Valley and the tributary valleys of the Koettlitz Glacier, we do find a till, but it is not elastic on account of the coarseness of the material, and can only be recognised as such by comparison with the basal moraine still in the glaciers.

In other places, as we have seen when discussing striated boulders, the natural end of the basal moraine is on the sea-floor, and the dredgings again show that such is the case. The clay is rather more definite in this case, as might be expected from the action of the sea-water and from the addition of marine organisms. In most of the dredgings the clay is naturally soft and washes free from the larger pieces, but in one haul off the edge of the Barrier pieces of a hard clay came up interspersed with grit and small pebbles. The clay itself contained many fragments of sponge spicules. Throughout Ross Sea there must be a continual rain of particles of all sizes from the bases of floating bergs, which is forming a thick bed of marine boulder clay. The occasional larger organisms in the shallower parts should be giving it a very definite marine character, for the large sponges and some of the corals are very durable.

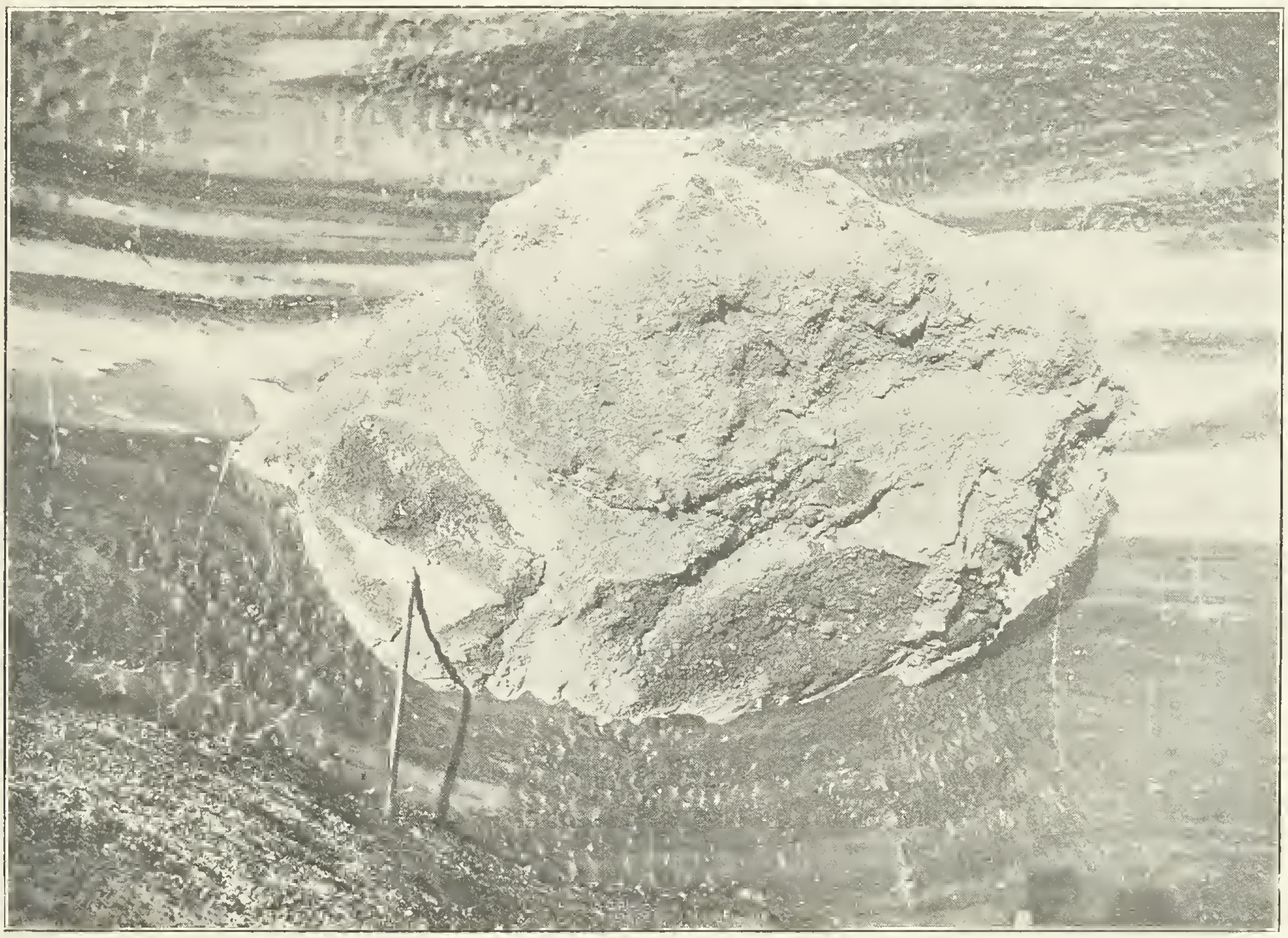


Fig. 19.—Tuff boulder in face of Barne Glacier. The bands are of very fine volcanic dust, capable of forming a true boulder clay. Note the grooving of the boulder due to differential movement.

SUMMARY.

The most general conclusion to be drawn from the preceding remarks is that the recent deposits due to polar conditions are comparatively small in amount, far smaller, for instance, than is the case in Greenland or Spitsbergen, and that the chief cause is the fact that the air thaw-point is very rarely reached. The thaw is, therefore, local, instead of universal as it is in the above-mentioned countries. In spite of that fact, however, thaw water does play an important part in the distribution of material and even to some extent in erosion. The deposits which have been transported by water are, however, difficult to recognise as such for two reasons. First, because the action of the wind is almost equally important and masks that due to water; and, secondly, because the deposits are very rarely bedded or composed of water-worn particles. One may legitimately infer from this that, where glacial deposits contain much fine material without bedding or rounded particles, they have been laid down under severe conditions of climate, which prevented the thaw water from exerting its maximum effect and increased the proportions of wind-borne material.

It is clear also from the above that a lake-deposit formed under these severe conditions is unlike that of a normal lake, and, except for occasional bedding and some remains of the lake flora, can hardly be recognised as such.

Occasional deposits of rough but even-grained material in a glacial series may further be recognised as due to wind alone, and several such were found in the South.

While it is impossible to state the correct proportion of deposits due to wind as opposed to water, there is no doubt that the former is of far greater relative value than under any other conditions except those of an arid, hot, desert region.

Coming to the deposits due to the action of ice alone, we find a new or, rather, an obscure process at work in the raising of marine muds. The conditions for the process are not confined to the Antarctic, and possibly it will be found to have been at work in the Arctic in many places. The quantity of material which might be transported in this way is small, but the kind of material is of great importance, for in it land and sea deposits are mixed up in a very irregular and puzzling manner.

The moraines of the Antarctic, while differing in a few characteristics from those typical of milder conditions, are formed in the same way, and the anomalies can be explained. The absence of high terminal moraines is a characteristic due to the climate, while the absence of true boulder clay is chiefly due to the lack of soft sedimentary rocks in the region. One may conclude that where the chief moraines are lateral there has been little differential movement in the glaciers.

The factor above all others which is responsible for the difference in these deposits from those of temperate regions is the height of the true snow-line, or air thaw-line, which is everywhere at or below sea-level.

3 SEP. 1921
BRITISH MUSEUM NATURAL HISTORY

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
DUKE STREET, STAMFORD STREET, S.E. 1, AND GREAT WINDMILL STREET, W. 1.

BRITISH MUSEUM (NATURAL HISTORY).

BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910.

NATURAL HISTORY REPORT.

GEOLOGY. VOL. I, No. 4. Pp. 101–130.

THE SEDIMENTARY ROCKS OF SOUTH VICTORIA LAND.

No. 4a.—THE SANDSTONE, ETC., OF THE McMURDO SOUND, TERRA NOVA BAY, AND BEARDMORE GLACIER REGIONS.

BY

F. DEBENHAM, O.B.E., B.A. (Cantab.), B.Sc. (Sydney), F.G.S.
Fellow of Gonville and Caius College, Cambridge. Geologist on the Expedition.

No. 4b.—THE SLATE-GREYWACKE FORMATION OF ROBERTSON BAY.

BY

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WITH EIGHT FIGURES IN THE TEXT AND ONE PLATE.

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[*Issued 26th November*, 1921.]

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No. 4a.—THE SANDSTONE, ETC., OF THE McMURDO SOUND, TERRA NOVA BAY, AND BEARDMORE GLACIER REGIONS.

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INTRODUCTION.

The reports * of former expeditions to South Victoria Land have described very clearly the general features of the coast which runs from Cape Adare in Lat. 71° S. to the Beardmore Glacier in Lat. 85° S. and is formed by the faulted escarpment of the Antarctic plateau. To the east lies the sunken area of the Ross Sea with a fairly uniform depth of about 2,000 feet (610 metres), and to the west is the plateau with an average height of about 6,000 feet (1,830 metres) above sea-level. Between the two there is a narrow strip of foothill country along most of the coast, varying from 2 to 20 miles in width; and it is from this strip that most of the information about the structure of the country is derived, for there only are the few outcrops of bare rock to be found.

The faulted edge of the escarpment is for the most part tilted upwards and the plateau behind is generally a little lower than the edge. A series of cross-faults have given rise to "horsts" in places, the blocks of which have been denuded into the form of peaks reaching a maximum height of about 15,000 feet (4,570 metres).

With the exception of the Cape Adare region (see p. 121) where the slates are strongly folded, the structure of the coast is horizontal and gives rise to a large number of tabular mountains which are the most remarkable feature of the topography when viewed at a distance. This horizontal structure is due to the level-bedded character of the main sedimentary formation of sandstone which has been stiffened by massive intrusions of a later dolerite in the form of very extensive sills. Since the base of this formation has been proved to be of Devonian age at least, we have to regard the whole area as one of great stability and freedom from lateral earth-movements. It is much fractured and there are local tilts of the strata, especially in the Beardmore Glacier

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* National Antarctic Expedition, 1901–4. Natural History. Vol. 1 (1907).
British Antarctic Expedition, 1907–9. Geology. Vol. 1 (1914), Vol. 2 (1916).

region, but the only folded rocks from Lat. 75° S. southwards are the foundation metamorphic series which are referred to the Pre-Cambrian age. The sandstone formation with dolerite sills has an enormous extension, for it is found in Adelie Land in Lat. 68° S. and Long. 150° E., and judging from Captain Amundsen's photographs probably also in Lat. 86° S. and Long. 170° W.

On account of the inaccessibility of many of the outcrops and the peculiarly barren character of the sandstones that constitute the chief horizon, palaeontological evidence as to the character and age of the sedimentary formations has been difficult to secure. The first discovery of value was made by the party under Sir Ernest Shackleton, who found fragments of a Cambrian limestone in the moraines of the Beardmore Glacier (see p. 118). The outcrop has not been found and from the specimens it appears possible that they come from the main horizontal sandstone formation of late Palaeozoic age, having been derived from Cambrian strata.

The only other fossil evidence as to the age of the formations are the fish-remains of Upper Devonian age found in the Granite Harbour region, Lat. 77° S., in morainic débris from the base of the main tabular series (see p. 109); and the plant-remains from the upper portions of the formation which were found by Captain Scott's Pole Party on the Beardmore Glacier and by R. E. Priestley in the Terra Nova Bay region, and have been referred to Gondwana age (see p. 111).

Volcanic action of Tertiary age is evident along most of the coast, with its two main centres in McMurdo Sound, and in the Cape Adare region from Lat. 71° S. to 74° S. This action has left sedimentary deposits of tuff in places, but these have so far yielded no fossil evidence, and it seems that most of those examined were deposited on land.

THE McMURDO SOUND REGION.

This region, extending from the Koettlitz Glacier in Lat. 78° 30′ S. to Granite Harbour in Lat. 77° S., is the best-known locality on the Antarctic continent, and is naturally taken as the type with which others may be compared. The geology of the mainland was first investigated by H. T. Ferrar of the National Antarctic Expedition of 1901–4, and the various journeys of that and other expeditions up the Ferrar Glacier have made that district familiar. On proceeding up the deep trough-like valley of the glacier one meets first the foundation rocks of Pre-Cambrian age, much folded and metamorphosed, then some twenty miles inland the dolerite sills, and finally above one of them, at a height of about 5,000 feet above the sea, is seen a yellow level-bedded rock, the sandstone, forming some of the summits of the massive Kukri Hills. Farther west this rock is seen in greater thickness, the lowest beds that are visible being about 3,000 feet above sea-level.

Some thirty miles farther north, a similar though broader valley, containing the Mackay Glacier, comes down from the plateau, and the sequence of the rocks as one passes up the valley is precisely the same. The sandstone formation is here a little lower, the lowest beds seen being about 2,000 feet above sea-level. The contrast of the yellow sandstone associated everywhere with the dark dolerite suggested to Ferrar the name Beacon Sandstone which is now used for the same formation wherever it occurs in South Victoria Land.

In the region under consideration the sandstone has very uniform characteristics. In the lower beds it is less pure as they contain bands of limestone a few inches in thickness and many thin beds of shale. Near the base the shaly bands grade into soft coal, and in one area, Granite Harbour, there is a shale of an earlier (Upper Devonian) age which is apparently conformable with the sandstone itself.

The total thickness of the sandstone formation cannot be stated definitely since the upper limit has never been observed. The base can be seen in one or two places but has not been examined closely. It is important to note that where the base can be seen it is resting upon a comparatively level bed of granite (see Fig. 1). In the Kukri Hills in particular the dolerite has intruded between the granite and the sandstone over a large area, raising the latter many hundreds of feet without much fracturing or tilting. The junction between the dolerite and the granite is extraordinarily even and horizontal, and since this was the former bed of the sandstone it seems to be established that the base of the formation was laid down on an even bed which had been degraded to base level.

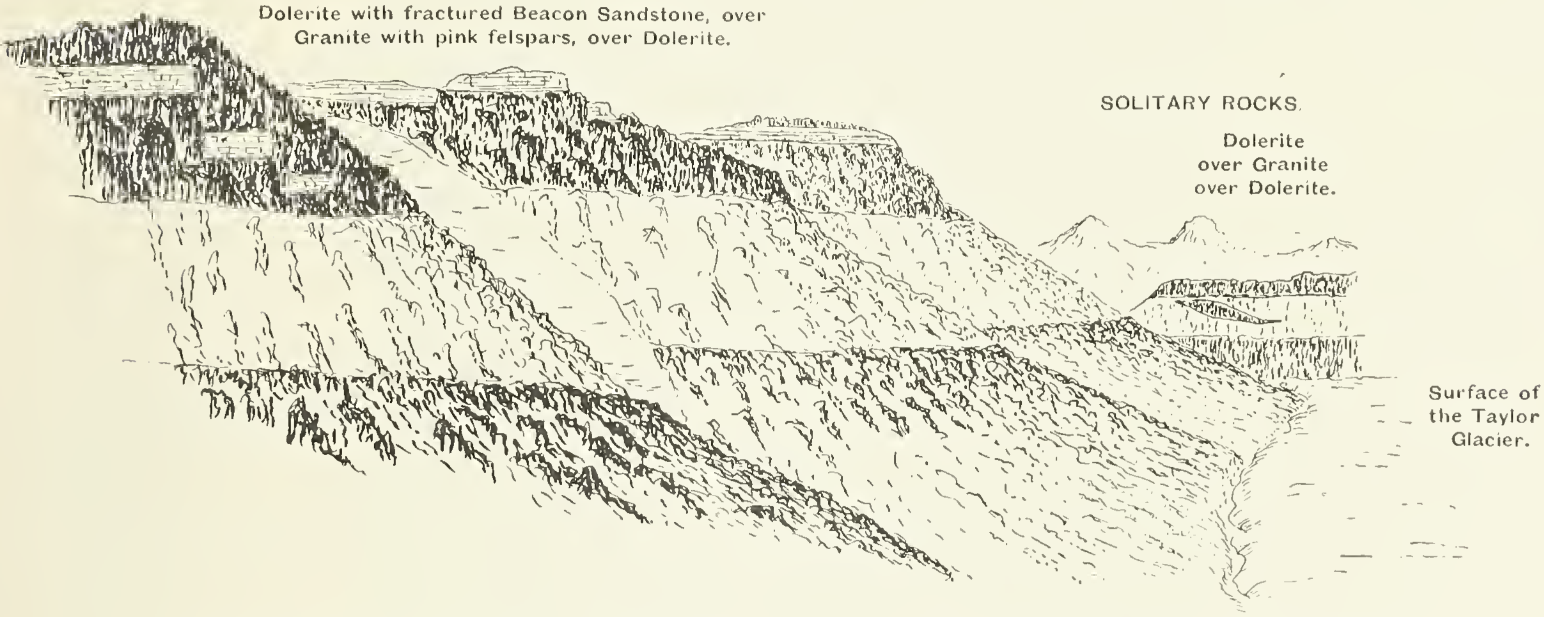
Dolerite with fractured Beacon Sandstone, over Granite with pink felspars, over Dolerite.
SOLITARY ROCKS.
Dolerite over Granite over Dolerite.
Surface of the Taylor Glacier.

FIG. 1.—Sketch of the north side of the Kukri Hills, Ferrar Glacier, looking west from a point above the snout of the Taylor Glacier. Hills about 3,000 feet above glacier surface, showing the level granite platform on which the sandstone was laid down.

At the Inland Forts, Ferrar* measured a thickness of the sandstone of 2,000 feet without seeing either the top or the bottom, and there is no doubt that the maximum thickness in the McMurdo Sound region far exceeds this figure.

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* Nat. Ant. Exp., 1901–4. Natural History. Vol. 1 (1907), p. 40.

In the bold escarpment of the Royal Society Range (see Fig. 2) the horizontal bands of the dolerite with the sandstone can be seen to a thickness of at least 5,000 feet. In the steep sides of Mt. Gran in the Granite Harbour area the level bedding is visible for a thickness of about 4,000 feet. In neither of these cases can we definitely see the upper limit of the sandstone as the caps of the mountains are either of weathered sandstone or dolerite. On the whole it may be said that the Beacon Sandstone is at least 3,000 feet thick in the McMurdo Sound region. It was noticed by Ferrar that the upper layers appeared to be more dense and consisted of more uniform layers of fine sand than the lower, but these terms can only be used in a relative sense since we do not know what the uppermost layers consist of. They are visible high up in the cliffs of the Royal Society Range but have never been visited.

In the absence of definite fossil evidence, variations in lithological character become of some importance in determining the mode of deposition of the sediments. Thus in some horizons of the sandstone there are a large number of short bands of pebbles and grits few of which seem to be continuous for more than a few yards horizontally and none of a thickness greater than one foot. The pebbles are in most cases much waterworn but occasionally are quite angular. In the Granite Harbour area, as Ferrar found at the Inland Forts, these pebbles are almost all of vein-quartz or hard quartzite, but in the moraine in the centre of Mackay Glacier a large number of coarse-grained specimens of the sandstones were found which contained pebbles of limestone. One of these in particular is angular but most of the others have been partially dissolved leaving a cavity lined with crystals of quartz and calcite. Unfortunately no sign of any fossil was found in this limestone, so it cannot be definitely referred to the same (Cambrian) age as the limestone pebbles of the Beardmore Glacier. Thin bands and patches of shale in the lower layers of the sandstone also furnish some evidence as to the conditions of deposit. They are mostly

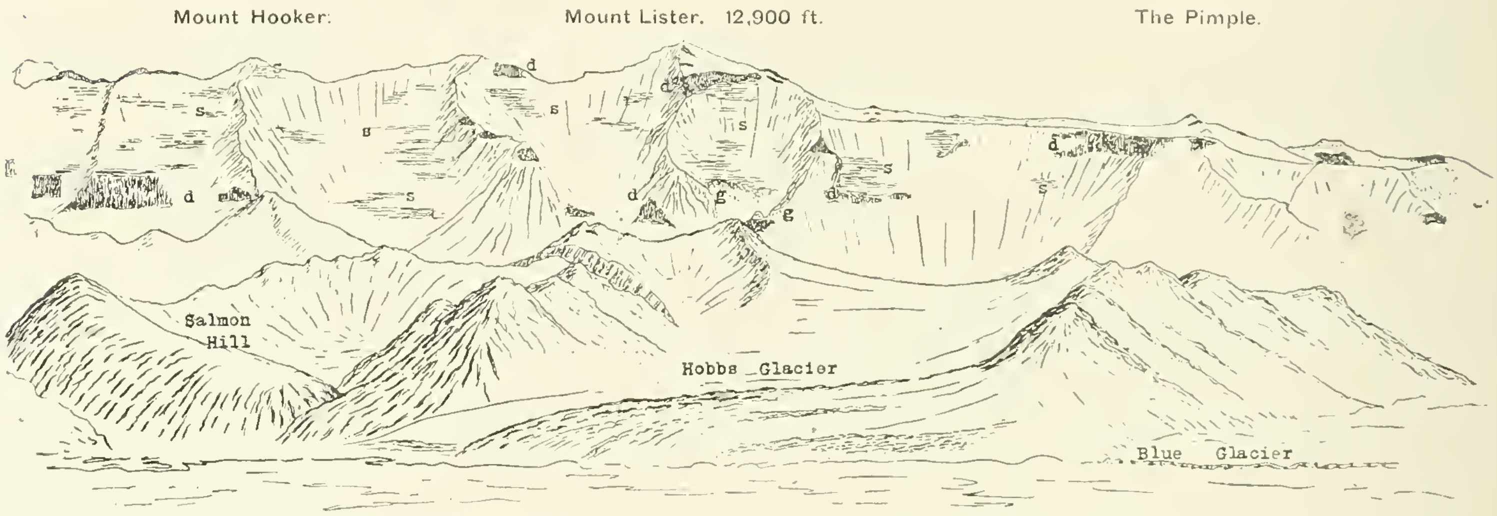

FIG. 2.—Panoramic sketch of the Royal Society Range showing the Beacon Sandstone resting on granites and intruded by dolerite sills. Sandstone marked s, dolerite d, granite g.

lenticular in shape and thin, suggesting that the mud was deposited in pools in the sand. More direct evidence of such pools and a comparatively dry climate with some rainfall is afforded by the ripple-marks and sun-cracks (Fig. 3) which were observed on the central moraine of the Mackay Glacier. It is not clear from the ripple-marks whether they were caused by wind or water, but it is immaterial as either would mean a sandy waste with occasional pools of shallow water.

The sandstone varies very much as to hardness and durability. Some layers are so dense as to outlast the dolerite while others are so friable that they crumble to the original sand at a touch. The cement for the most part is siliceous but on some horizons it is entirely calcareous. Prior * notes that the more compact layers have a large amount of siliceous cement which has recrystallized round the original grains in optical continuity with them. This points to heated solutions percolating through the sandstone, evidence of which is also afforded by the occasional occurrence in the rock of cavities filled with crystals of quartz wholly or partially replacing calcite.

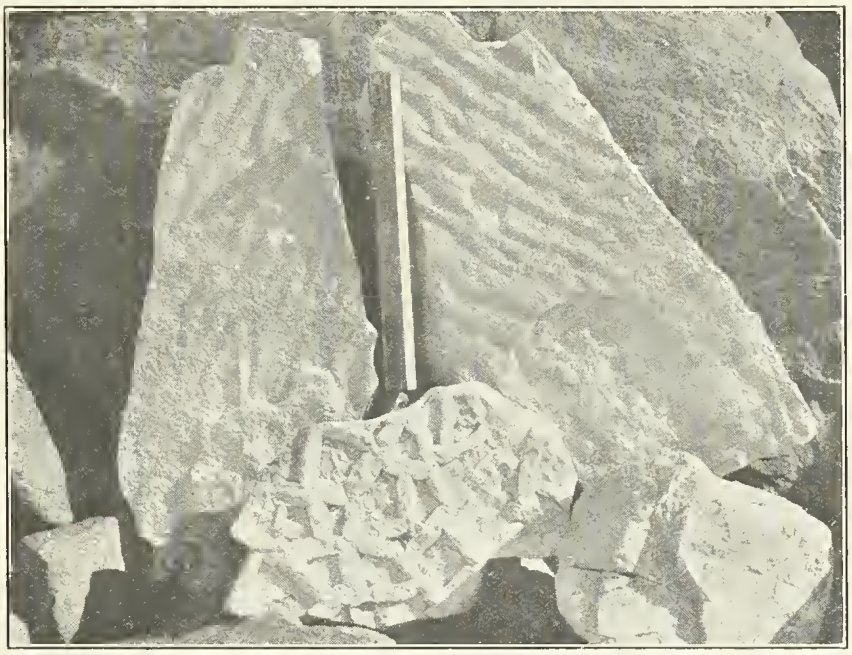

FIG. 3.—Ripple-marks and sun-cracks in the Beacon Sandstone.
From Mount Suess, Granite Harbour.

Evidence of considerable thermal action is manifest in other ways. Ferrar found much carbonized plant-material in the outcrops he visited, and in the last expedition large masses of charred stems were found both in the Granite Harbour region and in that of Terra Nova Bay. The stems are drift-material, as pointed out by Professor Seward, and occur both in the pure and in the shaly sandstone. A still more definite example of intense heating is afforded in the same regions by the large blocks of perfectly black sandstone, in which the colour is due to a dense bituminous cement. None of this rock

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* Nat. Ant. Exp., 1901–4. Natural History. Vol. 1 (1907), p. 134.

was found *in situ* but one naturally supposes it to be adjacent to the coal beds: much of it contains large nodules of pyrites. There appears to be no doubt that this charring and baking was due to the intrusion of the dolerite, probably in Cretaceous time.

Ferrar and David both refer to the occurrence of ferruginous concretions in the Ferrar Glacier area and the same thing occurs in other places to a less degree. In the McMurdo Sound region generally the Beacon Sandstone is fairly pure and usually of a white or light-yellow colour, but in the Granite Harbour area a great deal of it is coloured green, either throughout or in patches, owing to the presence of chlorite.

With regard to the constituent grains there is also a good deal of variety. The pure white stone is composed almost entirely of clean quartz grains, in some cases so much rounded as to suggest wind- rather than water-action. In other cases the grains are distinctly angular, though one must be careful to distinguish fractures of the original grains by pressure and heat from initial irregularity due to lack of erosion. Secondary fractures are particularly clearly seen in some of the very much indurated samples from the neighbourhood of the dolerite.

In the more discoloured specimens the grains are seen to be of a more varied character. Quartz is still the dominant mineral, but fragments of very fresh-looking felspar, mica, and other aluminous minerals are present, together with grains of garnet, apatite, and rutile. In the coarser layers fragments of mica-schist are found. It would seem, therefore, that the material of the Beacon Sandstone in the McMurdo Sound region was largely derived from granites, to a less degree from the metamorphic series, and to a still less degree from a limestone possibly belonging to the same formation as the Cambrian limestone of the Beardmore area.

The small amount of cementing material, the freshness of the felspars, and the general absence of red oxides of iron are all noticeable features and seem to point to very dry conditions. The false-bedding may be due either to wind or water, and the abundant evidence of pools and stranded plant-material establishes the existence of water in small quantity.

The coal beds in the Granite Harbour area (Fig. 4) were unfortunately not visited *in situ*, as they were seen only in inaccessible places. They undoubtedly occur towards the base of the whole formation in company with moderately thick beds of shale, and we therefore have evidence of a gradual change of climate during the deposition of this great thickness of material.

The fragments of coal which were picked up on the central moraine of the Mackay Glacier were all similar in character. It is a hard bright coal and is associated with a dark soft shale. The coal consists almost entirely of fixed carbon with a high percentage of ash. In it are found charred fragments of stems which are unrecognizable. The specimens bear all the marks of having been subjected to high temperature, and the absence of any noticeable amount of volatile hydrocarbons supports this suggestion. The finding of sandstone impregnated with bitumen seems to complete the story. One or two of the smaller fragments appear to be of better quality, but one is forced to recognize that probably the dolerite has destroyed most of the coal beds in this area and reduced them to what is the equivalent of anthracite with an excessive amount of mineral ash. The larger specimens have almost a slaty cleavage, which was no doubt due in part to the loss of its volatile constituents while under pressure. The Beardmore Glacier coal, on the other hand, has not undergone such a baking, for in this the volatile constituents reach 14·5 per cent., fixed carbon 68 per cent., and ash 13·5 per cent.*

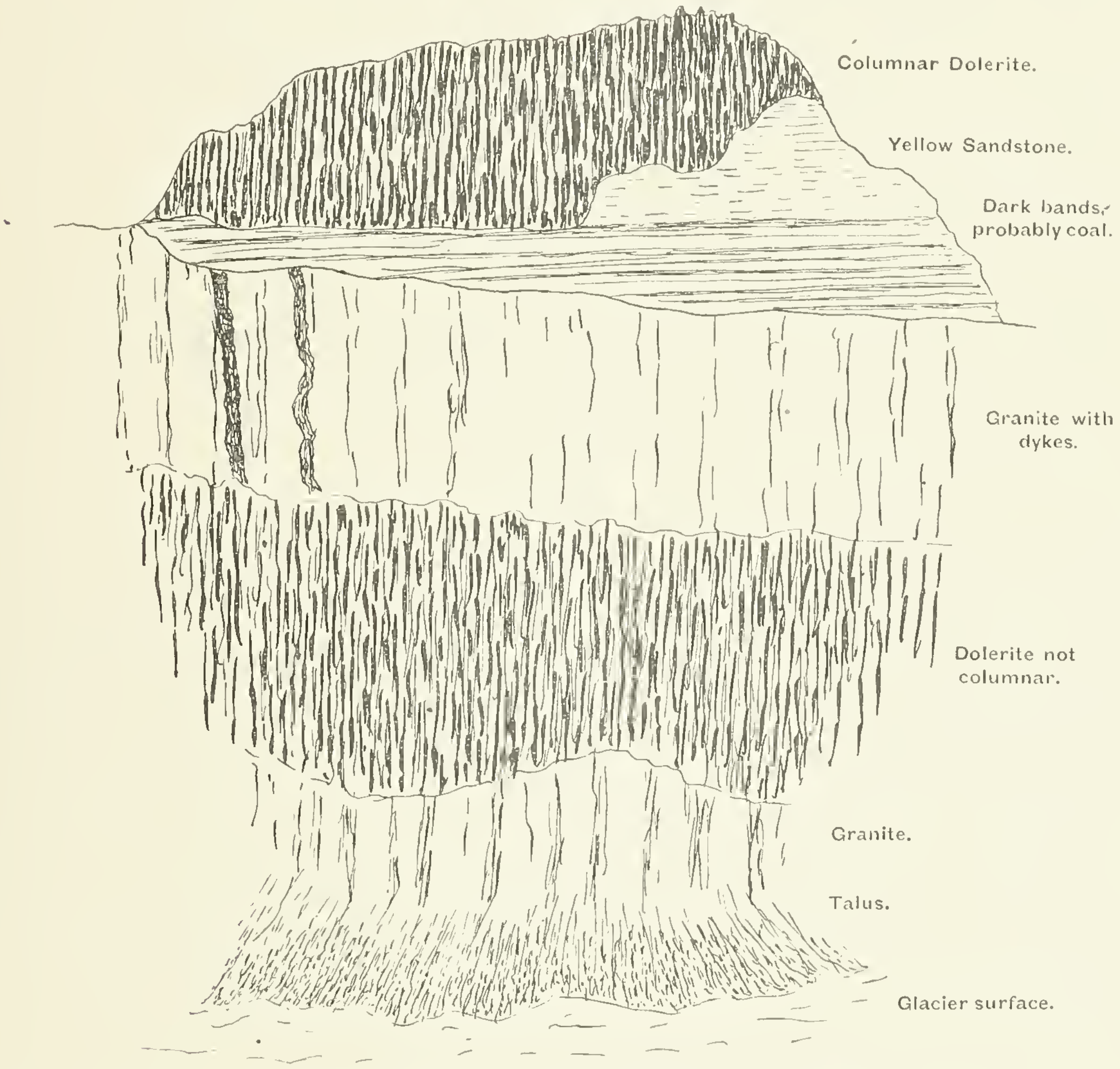

FIG. 4.—Cliff-section on the south side of the Mackay Glacier, Granite Harbour region. Total height of cliff above glacier about 1,200 feet.

On the same moraine of the Mackay Glacier were found the remains of fish which have been described by Dr. Smith Woodward in No. 2 of this volume, and have been referred by him to Upper Devonian age. These occur in pieces of shale and shaly sandstone which are identical in outward appearance with the bands of shale that are found in the lower layers of the Beacon Sandstone, both in Granite Harbour and in the Depôt Nunatak on the Ferrar Glacier. In one case the fish-scales are in a finely laminated shale, but generally they are in irregular pieces of rock which has no definite cleavage and contains a good deal of rather coarse sand. As none of the fish-remains were found *in situ*, the problem is to make room for the Upper Devonian horizon between the granite floor of the formation and the coal beds which, in view of the definite proof of Gondwana age for the Beardmore coal, one provisionally places on the same horizon. For the present it may be assumed that the base of the formation contains a thin series of Devonian sediments, and that there is no marked unconformity between them and the Permo-Carboniferous series of shales and sandstones. One is tempted to add that the conditions of deposit were also somewhat similar, for the sands of the fish-scale specimens are precisely similar to those of the upper layers. It is hardly likely that the fish-scales can have been derived from a Devonian deposit elsewhere, and have been included unharmed amongst the products of erosion that built up the Beacon Sandstone.

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* British Antarctic Expedition, 1907–9. Geology. Vol. 1 (1914), p. 250.

THE TERRA NOVA BAY REGION.

This is a convenient name for the area between 74° 30′ S. and 75° 30′ S., in which the most commanding feature is the tabular mass of Mount Nansen, marking the edge of the continental escarpment. Other features are the symmetrical cone of the extinct volcano of Mount Melbourne to the north-east, and the peculiar sheet of ice known as the Drygalski Glacier Tongue which bounds the area on the south side and represents the confluence of several large glaciers coming from the vicinity of Mount Nansen.

The evidence for a discussion of the sedimentaries of this region is somewhat slender. The area has been visited by two parties, one under Professor Sir T. W. Edgeworth David in 1908, and one under Lieut. Victor Campbell, R.N. in the summer of 1912. In neither case were the geologists able to reach sedimentary rocks *in situ*, but they made collections from the large glacial moraines.

The sequence of the rocks seems to be identical with that found in the McMurdo Sound region. On the coast are the low islands and foothills composed for the most part of the foundation metamorphic series of gneisses, schists, and granulites. Intruded through these and forming the bulk of the higher foothills are the granites which will be discussed in No. 6 of this volume. High up on the Mount Nansen *massif* and on the mountains to the north of it can be seen the familiar level-bedded appearance due to the Beacon Sandstone formation, intruded by dolerite sills as in the McMurdo Sound region but to a less extent. It is not possible to estimate the thickness of the formation with any accuracy, but from the evidence of photographs and from the field-notes of the geologists it can hardly be less than 2,000 feet, that is to say, it is of the same order of thickness as farther south.

Little more than this bare estimate of thickness can be said of the formation *in situ*, as it has never been approached nearer than ten miles, and for further description we have recourse to the specimens collected from moraines. A large number of these were obtained by Priestley who was the geologist of Campbell's party, and it is worthy of note that nearly all of them were collected from the southern and western side of the moraines of the Priestley Glacier. This suggests that on the northern side there are no outcrops of the sandstone and that there is a fracture along the line of the glacier valley which has hidden the formation.

With regard to the specimens, Priestley noted the striking resemblance they presented to the sandstones of the Ferrar Glacier valley. There are the same coarse conglomerates, coarse yellow sandstones, and felspathic grits; and the same variation from almost pure quartz sandstones, extremely hard and dense, to friable uncemented rocks with much decomposed material. On the other hand, the proportion of impure sandstones is much greater, ranging from yellow sandstones with scattered grains of carbonaceous material, to dark-brown grits with much volcanic débris as well as the almost universal fragments of stems. Unfortunately these plant-remains, although abundant, were in most cases much charred by heat. A few petrified specimens were obtained, however, and these have been described in No. 1 of this volume by Professor A. C. Seward who, from the petrified stem (*Antarcticoxylon Priestleyi*) and from a winged spore (*Pityosporites antarcticus*), has referred them to an early Mesozoic age.

We have seen that the shales associated with the Beacon Sandstone formation in the McMurdo Sound region are of Upper Devonian age and they are undoubtedly at the base, so that we arrive at a provisional estimate of the age of the formation as late Palaeozoic, stretching into early Mesozoic. Unfortunately the quality of the evidence so far does not warrant our placing the age with any greater certainty than this, but we may without much doubt conclude that the Devonian horizon is of small thickness and that the coal-measures, or Permo-Carboniferous series, is of the greatest thickness. It appears that the Terra Nova Bay region is remarkable for a greater extension of the later sediments than is found farther to the south.

It should be noted also that in one of the specimens collected from the coal-bearing horizon of the Beardmore Glacier region was found a fragment of coniferous wood which appears to be comparable with those found on the Priestley Glacier moraine.* Although no specimens of coal were picked up from this moraine, coal is probably present in the sandstone series of the region, for not only is it much too fragile to bear transport for great distances but its similarity of colour to the basaltic rocks which are frequent in the moraines makes its discovery a matter of difficulty.

The strong probability of the presence of coal is also suggested by the occurrence of bituminous sandstones of exactly the same type as in the Granite Harbour district. These are somewhat felspathic sandstones containing many charred fragments of stems, and the whole rock is so impregnated with bitumen that it is quite black, the grains of quartz and felspar standing out clearly in a shining matrix of the bitumen. One or two of the specimens gave off a distinct bituminous smell on being brought to red heat, but in most cases the black product appears to be carbon, as it has lost all trace of volatile constituents.

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* "The Heart of the Antarctic." E. H. Shackleton. 1909, vol. 2, p. 300.

The occurrence of the charred fragments with the bituminous impregnation gives rise to a peculiar problem. The woody stems are evidently the result of drift, since they are distributed irregularly through the rock, and we may imagine estuarine sands which occasionally received floods as the original state of this area. But the stems could hardly remain in a fresh state for a very long period and the charring must have taken place within a reasonable time of their deposition. The heating of the coal beds which drove off the volatile constituents into the surrounding sandstone must have occurred at a much later time presumably. In fact in the Granite Harbour district it seems to be correlated with the intrusion of the sills of dolerite which must have happened late in Mesozoic time. It seems, therefore, that we have to postulate two periods of heating of the beds.

In the Terra Nova Bay series of sediments we meet with a type of rock which is not found in the more southern areas, viz., very coarse tuffs. These form an extremely interesting series and their age seems to be definitely fixed as that of the Beacon Sandstone from the fact that they also are loaded with charred fragments of stems, and in places with angular fragments of quartz similar to the coarser varieties of the sandstone. They therefore point to a period of volcanic activity coincident with the deposition of the sands. They contain also fragments of a green chert. Further reference to these tuffs will be found in the chapter on volcanic rocks.

We are now perhaps in a position to venture some suggestions as to the conditions under which the greater part of the typical Beacon Sandstone was laid down. In the first place the climate seems to have been arid. The freshness of the felspars and other less stable constituents of the sandstone points to this, and it is supported by the comparative barrenness of the rocks, except those close to the coal bed horizon. The extremely rounded appearance of the sand-grains on some horizons appears to postulate considerable wind-erosion, while the presence of coarse and ill-sorted grits at other levels also seems to argue the absence of running water. The existence of ripple-marks and sun-cracks (see Fig. 3), as well as the frequent lenticular beds of fine mud, requires the occurrence of occasional pools in the sandy waste. The false-bedding which is very characteristic of the more barren sections of the sandstone seems to be evidence of a dune formation. On the other hand, the thin beds of limestone found particularly in the Ferrar Glacier district point to the near neighbourhood of a coast-line or large bodies of water. These seem to occur more frequently towards the base of the formation.

Speaking more particularly of the McMurdo Sound area we may perhaps imagine the conditions as follows. At the close of the Devonian period the area was rising from the sea which had held the fish the remains of which are found in Granite Harbour rocks. There was a wide expanse of low coastal country and the climate was not at first quite arid. Occasional changes of level allowed thin bands of limestone to form in amongst the expanse of sand-dunes that formed the greater part of the area. Conditions of climate then altered sufficiently to allow of the growth of swamp and bog plants and the formation of beds destined to turn into coal, but these conditions gradually gave place to those of great aridity involving the return of the wave of sand. The sand was derived, partly by water and partly by wind, from the uplands, apparently to the west of the area, which were composed of the metamorphic series and numerous acid plutonic rocks. Rivers from the more favoured uplands crossed the sand area with continually shifting beds, bringing coarser gravel and pebbles as well as broken stems of vegetation in their flood periods. But on the whole the conditions must at this time have been unfavourable to a vigorous growth of vegetation even in the uplands. Towards the north, volcanic activity produced a local variation in the deposits, but for the most part the conditions were very uniform over a large extent of country.

We cannot tell how the period ended for the upper limits of the deposits have not been seen, but it is certain that the area must have remained above sea-level for most of the time since the close of that period as there is no sign anywhere of later deposits, and the Beacon Sandstone itself has been heavily eroded.

The conditions towards the Beardmore Glacier appear to have been slightly different, but there is far too little evidence upon which to build any hypothesis as to the climatic relations between the two regions.

It should be added that although there seems to be a definite break in the continuity of the Beacon Sandstone formation between the Terra Nova Bay region and the Cape Adare district, yet it does apparently continue in a northerly direction, for it occurs in massive cliffs in Adelie Land as found by one of the parties of the Australasian expedition under Sir Douglas Mawson in 1912.

THE BEARDMORE GLACIER REGION.

This region may be taken as extending from about 83° 30′ S. to 85° S. on the 170th meridian E., following the line of the great glacier discovered and traversed by Sir Ernest Shackleton in 1908 and used by the parties under Captain Scott on their way to the Pole in 1911 (see Map, Fig. 5).

This vast outlet for the plateau ice-sheet is at least 130 miles long and for about 100 miles of its length is enclosed by valley-walls rising well above the stream itself and presenting steep slopes, many of which show bare rock. Its average width is about 20 miles, though in one place it is under 12 miles. The greater part of its surface is much disturbed by crevassed areas, particularly on the eastern side where

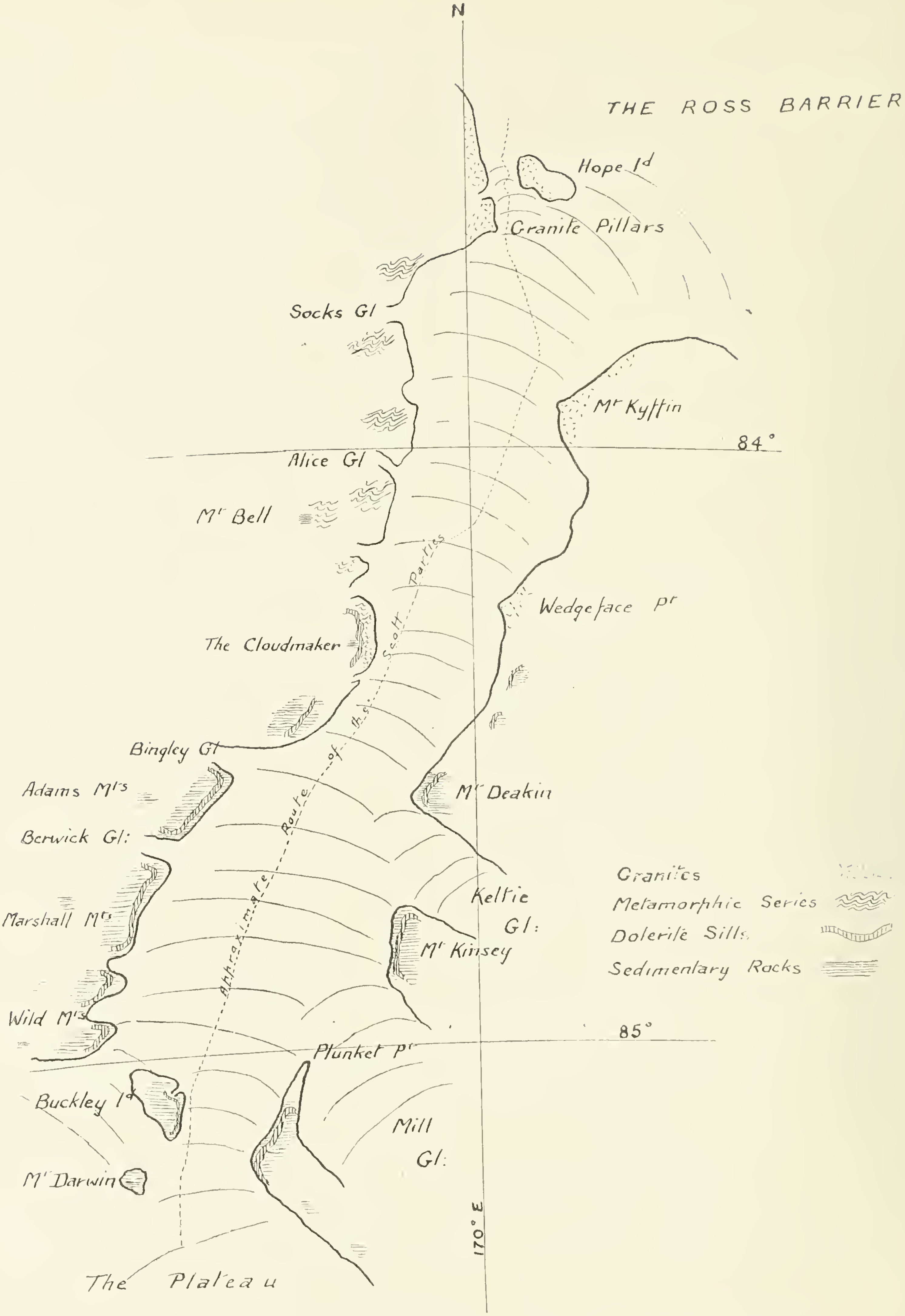

Fig. 5.—Sketch-map of the Beardmore Glacier. (Scale approximately 10 miles to the inch.)

two very large tributaries enter, so that the route to the summit is a circuitous and arduous one.

The glacier is thus briefly described in order to account for the extreme paucity of the geological evidence that we possess about this region. Although four parties have now traversed it from end to end, the rocky sides of the valley have as yet only been visited in three places. These are, the Granite Pillars and Mount Hope at the foot of the glacier, the Cloudmaker mountain half way up, and Buckley Island, a large nunatak rising above the ice, at the summit. The collections from these places, together with specimens picked up from the moraines on the glacier itself, supply all the direct geological evidence that we possess. No trained geologist has been a member of the parties, but with the aid of the photographs of Mr. C. S. Wright and others of those parties and of the extraordinarily accurate pencil sketches of the late Dr. E. A. Wilson it is possible to make some general remarks about points that have not been visited. Some of these generalizations are made on analogy with better known parts of the continental escarpment and may be accepted without much doubt. For instance the mountains at the lower end of the valley are in general irregular in shape and distribution with a tendency to a rounded outline, but with many sharp comb-ridges. This is a topography which is typical of the plutonic and metamorphic rocks as seen in the foothills of the Royal Society Range in the McMurdo Sound region. Above the Cloudmaker, on the other hand, the mountains are tabular in form and the valleys are straighter, while the steep slopes are either uniform or evenly-terraced. This is a topography that is common all along the escarpment, caused by the almost universal capping of level-bedded strata of the Beacon Sandstone.

But when the only evidence is the colour of the rocks as seen at a distance the identification is less certain, except where taken in conjunction with Wilson's sketches, often made with aid of binoculars, in which the typical forms of weathering are a fairly sure guide.

The first point that strikes a geologist who knows the other regions is the great similarity in both the facies and the distribution of the rocks in this area to those in the McMurdo Sound region. In the lower glacier we meet with the same types of foundation metamorphic rocks intruded by younger granites as those which form the Kukri Hills in Lat. 77° 30′ S. At the Cloudmaker, half way up the glacier, we come to the first signs of the sedimentaries, just as at the Cathedral Rocks on the Ferrar Glacier Very clear stratification can be seen at the summit of Mount Bell at a height of about 9,000 feet above sea-level, while in the Cloudmaker itself appear the dolerite sills which are such constant associates of the sedimentaries farther north. The lower sill appears to be about 6,000 feet above sea-level, and there is an upper less well-defined sill near the summit with indications of thin beds of sedimentaries above it, that is, at about the same height as those on Mount Bell. a few miles to the north. From the talus slopes at the base of the mountain, "slaty rocks with reef quartz" were collected by Shackleton. Southward and westward of this point the sedimentaries appear in a truly grand series of massive beds intruded by several sills of the dolerite. They have a very uniform dip to the south-west, that is, towards the plateau, precisely in the same way as the Beacon Sandstone series does in the upper Ferrar Glacier.

The Adams, Marshall, and Wild Mountains present steep faces towards the main glacier, showing a magnificent section of the whole of the sediments, but unfortunately the route trended away from these mountains and only distant views were obtained.

The thickness of the series cannot be less than 4,000 feet and may well be 6,000 feet. It consists of alternating light and dark bands intersected by the very dark dolerite. As seen in the photograph (Fig. 6) it is precisely similar to the formation on the upper Ferrar Glacier, and the sketch by Dr. Wilson (Fig. 7) incidentally shows what a very great deal a keen observer like Dr. Wilson could do in the absence of more accredited geologists. The "unconformity" is an instance, so common in the McMurdo Sound region, of the differential lifting of the sedimentary beds by the intrusions of dolerite.

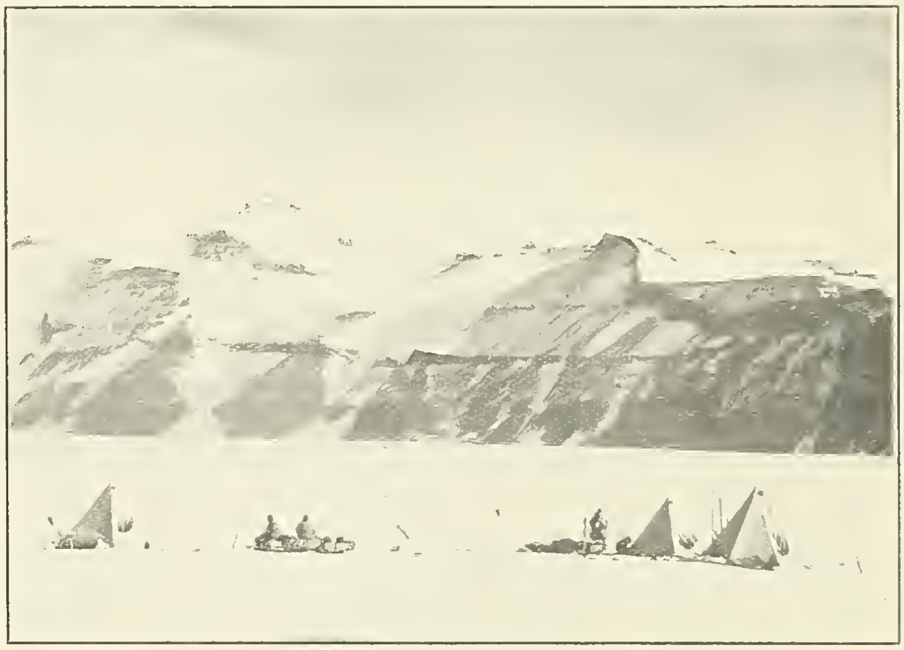

FIG. 6.—Wild Mountains, Beardmore Glacier, showing the Beacon Sandstone formation with its intruded sills of dolerite.

On the eastern side of the glacier the same section is apparent, but is more broken up by the intersection of sills, and not so continuous because of the large tributaries which enter on that side. On both sides the dip is less than 5 degrees to the south-west except at one place near the summit at Plunket Point, which is carefully noted and sketched by Wilson, where over a small area the dip of the sediments is about 10 degrees to the east. That this is a local faulting or displacement is proved by the fact that in the same sketch appears the regular slight south-westerly dip of the main mass.

At Buckley Island, where the surface of the glacier is nearly 6,000 feet above sea-level, one is well above the base of the sediments, which appears to be about 9,000 feet high at Mount Bell, and it is from this locality that most of the direct information comes.

A very full description of this outcrop is to be found in No. 1 of this volume by Professor Seward, which treats fully of the *Glossopteris* flora found there in association with the coal beds.

The sandstones which are in abundance in these beds are for the most part very similar in lithological character to the Beacon Sandstone from the McMurdo Sound region. They are distinctly more calcareous and have a far larger proportion of shaly beds intercalated, but their mode of derivation seems to be in the main similar. Some specimens containing comparatively little-altered grains of felspar suggest derivation from granitic masses, others again are composed almost entirely of quartz, although the very even-grained pure and hard quartz sandstone of the Ferrar Glacier region does not appear to be present on this horizon.

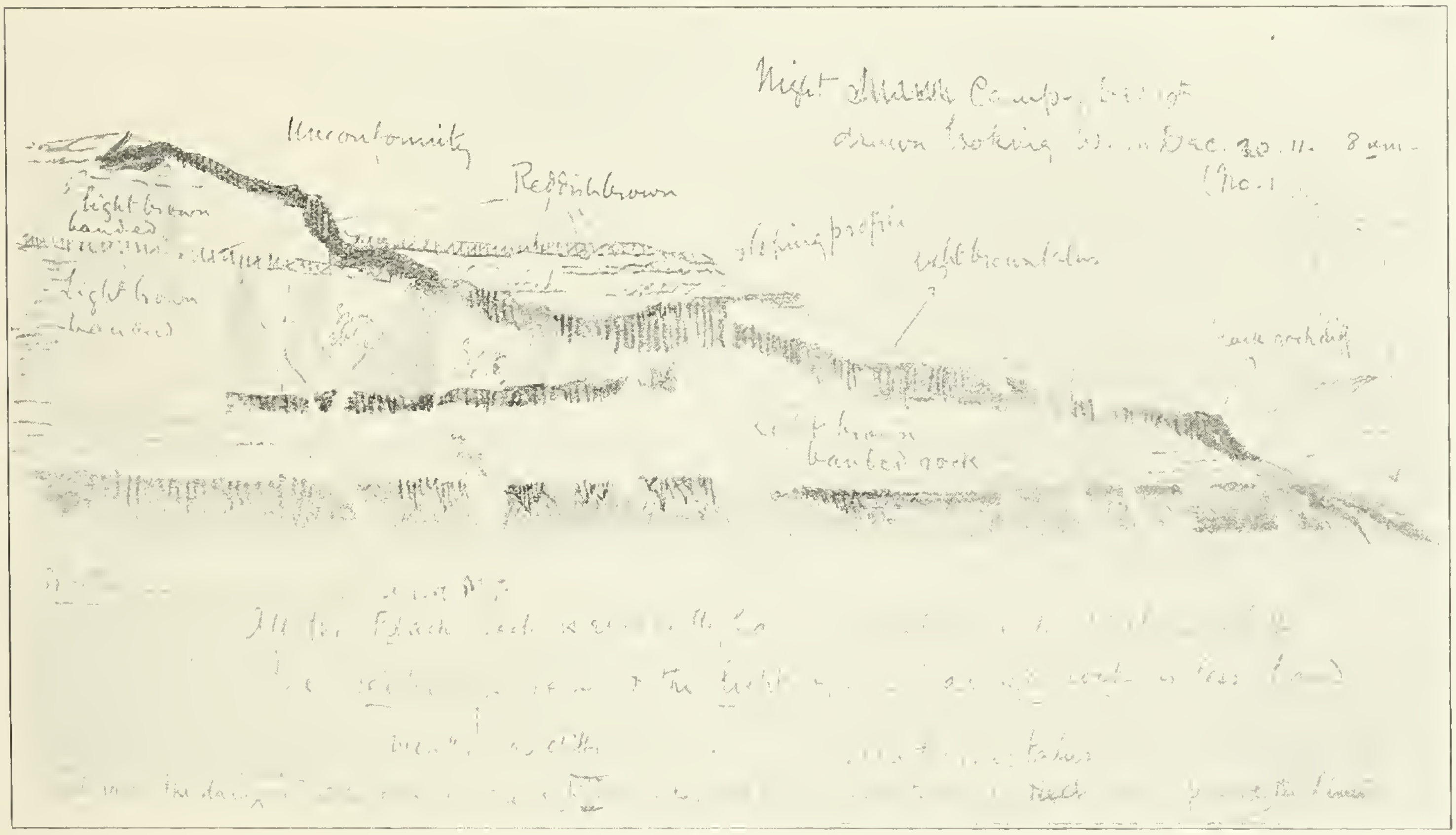

FIG. 7.—Sketch of Wild Mountains by Dr. E. A. Wilson.

Lithologically then we must agree with the verdict of Professor David that we have the equivalent of the Beacon Sandstone here. The impure grey limestone which forms a good proportion of the specimens from Buckley Island is somewhat similar to that found in the Granite Harbour region, being, as there, often associated with hard shales on the one hand and calcareous grits on the other. No specimens of pure limestone are recorded from this place. The moraine from Mount Darwin, a nunatak still further to the south, shows the same sequence of rocks with a preponderance of calcareous sandstone which in the distance has a pink appearance.

There is no unconformity to be seen in any of the photographs nor is it anywhere noted, with the exception of the faulted block on Plunket Point, and this corroborates the idea of the extraordinary stability of the whole of South Victoria Land suggested by the observations made in the more northern regions. Yet it would be very dangerous to conclude that this four or five thousand feet of sediments represents a single geological period, the Permo-Carboniferous, as determined by the *Glossopteris* flora on one of the horizons. If we are right in assuming from the evidence of the fish-remains in Granite Harbour and the fragments of stems in the Terra Nova Bay region that the Beacon Sandstone formation of those places stretches from late Devonian to early Mesozoic time we must be prepared to accept the same for the Beardmore area as well. There is nothing reported from this region that can be definitely asserted to be younger than the Beacon Sandstone except the dolerites; but fragments of lavas found in the moraines seem to show that only search is required to show the presence of the equivalent of the McMurdo Sound volcanics in this district also.

On the other hand, there is the very best evidence for the existence of earlier sediments somewhere in the region. In 1908 a fragment of a brecciated limestone was picked up in the moraine near the Granite Pillars at the lower end of the glacier and many much larger fragments were reported there. This proved to contain embryonic forms of the Cambrian fossil coral *Archaeocyathus*.*

This discovery had a curious confirmation in the dredgings of the *Scotia* in the Weddell Sea on the other side of the continent for in them were found specimens of a white limestone containing *Archaeocyathus*.†

The last expedition has also confirmed the discovery in the Beardmore region but again only from specimens gathered from the moraines.

The interesting point about these discoveries is that so far the fossils have always been found in a coarse breccia of limestone fragments, very dolomitic in character and held together by a lighter calcareous cement which includes also fragments of sandstone, angular fragments of quartz, and shale. As far as can be ascertained none of the fragments have been picked up above the Cloudmaker, and certainly they all seem to belong to the western lateral moraine. That would lead us to suspect an origin from the very base of the sediments as seen in Mount Bell, since the base only comes above the glacier surface about there. That there is a definite Cambrian horizon there, however, is very uncertain, and, in view of the fact that only a breccia of peculiar character has been found as yet with these fossils, Professor David's suggestion is possibly correct that the breccia was at the base of the Beacon Sandstone formation and was derived from strata in another locality. At any rate there seems no good reason for suggesting, as was done by one of the original discoverers, that the calcareous limestone of Mount Darwin on the summit is the parent of these breccias, for Mount

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* British Antarctic Expedition, 1907-9. Geology. Vol. 1 (1914), pp. 235-243.

† Scottish National Antarctic Expedition. Trans. Royal Soc. Edinburgh, 1920, vol. 52, pp. 681-714. Cambrian Organic remains from the Weddell Sea. By W. T. Gordon.

Darwin appears to be merely a continuation of the sandstone beds of Buckley Island as it has the same appearance and gentle dip to the south-west.

On the evidence at hand, therefore, we regard the Beardmore region as very similar in structure and history to the greater part of the plateau escarpment of South Victoria Land, with its universal level-bedded sandstone formation resting on a foundation of plutonics and Pre-Cambrian rocks.

No. 4b.—THE SLATE-GREYWACKE FORMATION OF ROBERTSON BAY.*

BY

R. H. RASTALL, Sc.D., M.Inst.M.M., F.G.S.

University Lecturer in Economic Geology, Cambridge.

AND

R. E. PRIESTLEY, M.C., B.A.

Geologist on the Expedition.

INTRODUCTION. (R.E.P.)

In February 1911, the Northern Party of the Scott Antarctic Expedition of 1910–13 was landed at Cape Adare, Robertson Bay, to occupy its time surveying this region until it could be picked up and transferred to a more favourable area. During the year attempts were made to sledge northward along the coast towards Smith's Inlet and Cape North, but these were frustrated by unfavourable ice conditions.

As late as August breaks in the sea-ice north of the bay were taking place continually, the whole sheet being constantly on the move. The pools, leads, and "polynia" that were continually being opened up by the screwing of the "pack" and by the frequent gales of hurricane force were at once covered over with a tough skin of new ice which rendered sledging and boating alike impossible.

Under the circumstances, the attention of the sledge parties was necessarily confined to the relatively inaccessible shores of Robertson Bay. Several trips were made south and west from Cape Adare, but all were comparatively short as can be seen from the accompanying map (Fig. 8, p. 122). The observations made during this spring and early summer are therefore strictly local in their application. They are, however, of interest because they apply to a portion of South Victoria Land structurally different from the other regions to the south which have been examined in some detail by the British expeditions.

This difference probably also applies to the regions to the north, for the country north of Smith's Inlet, although presumably exposed to almost the same weathering and denuding agencies (though possibly exercised in rather different proportions owing to climatic variation), is of an entirely different type.

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* In No. 4b, R. H. Rastall has described the specimens, and R. E. Priestley has supplied the notes on the field-geology.

Robertson Bay is bordered on its west, and older, side by the Admiralty Range of mountains comparatively little dissected and with the spurs of their foothills dipping steeply to the sea. This range differs markedly in its broader external characters from the portions of the Antarctic horst both to the south and to the north. Its only near analogue can be seen in the Royal Society Range which has Mounts Lister and Huggins of about the same order of height as Mounts Minto and Adam in the Admiralty Range. To the south a much lower phase is seen in the tabular mountains

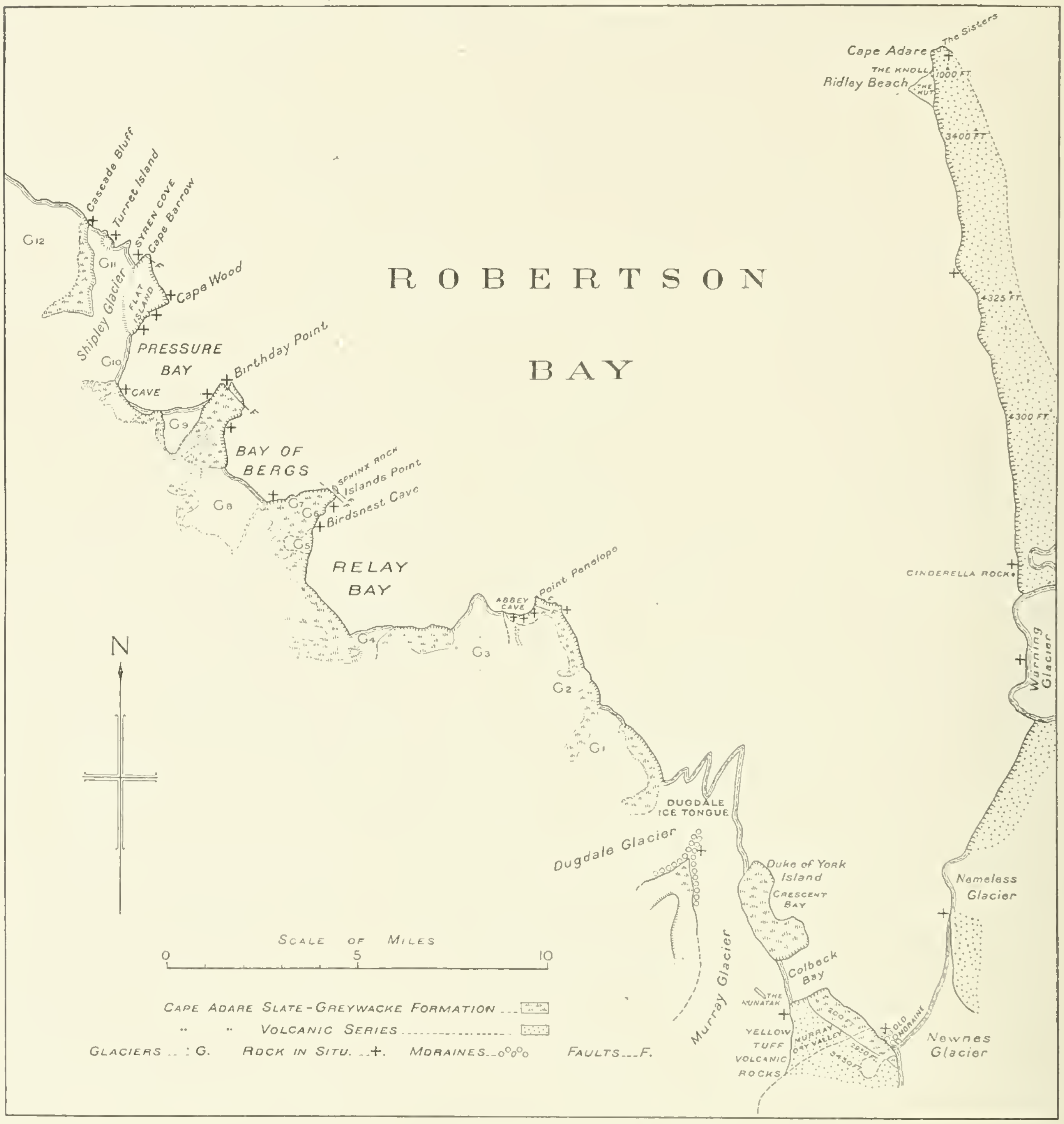

FIG. 8. Map of Robertson Bay region.

whose most northern representatives visible from the coast are Mounts Larsen and Nansen and which owe their characteristic shape to the fact that they are capped by the horizontally-bedded Beacon Sandstone.

To the north of Smith's Inlet again, the mountains are also much lower and they are bordered on their seaward side by a broad plateau, one or two thousand feet above sea-level, which is strongly suggestive of a fault parallel to the main coastal fault bordering the sunken area of the Ross Sea. A long strip several miles broad seems to have been dropped some thousands of feet in relation to the main horst behind.

It was unfortunate that heavy pack-ice prevented a nearer approach in this latitude, for the country, in addition to its greater interest tectonically and probably petrologically, appeared much more accessible to sledging parties than that immediately round Cape Adare.

The question arises, in view of the main features of the geology of the Cape Adare region which are touched upon in the following pages, whether the foothill region, at any rate, of the Admiralty Range belongs essentially to the same tectonic unit as those regions farther to the south which have been examined. In the Beardmore Glacier, the Koettlitz-Ferrar area, the Granite Harbour region, and the Terra Nova Bay district, the essential formations are practically the same, though differing somewhat in facies as might be expected. The resemblance is very striking leaving no doubt of the tectonic unity of the whole coastline from 85° S. to 74° S. In Adelie Land, again, the Mawson Expedition has proved the existence of the Beacon Sandstone formation, the dolerite sills, the granite intrusions, and the Archaean basal complex.

In the Robertson Bay area, however, the most striking of these formations—the first and last mentioned above—are conspicuous by their absence except for one or two possible examples in the high-level moraines which belong to a period of far greater glaciation than the present.

The scanty evidence for and against the hypothesis that the whole of this somewhat important region consists of a great boss flanking the old Continental Shield of East Antarctica will perhaps be better seen after a short description has been given of the formations actually present. It is the only geological problem of any great interest which awaits solution in this particular area. Other observations, and particularly those pertaining to the later tectonic history of the area, are simply confirmatory of much that is now known with fair certainty from the other areas mentioned.

Whatever may be the truth about the early history of the district, it is certain that in Tertiary and Recent times it has behaved as a portion of the main South Victoria Land complex. For instance, it has taken part with the latter in the block-faulting with accompanying volcanic activity which produced amongst other marked features the South Victoria Land horst and the sunken area known to geographers as the Ross Sea.

GENERAL DESCRIPTION OF THE SLATE-GREYWACKE FORMATION.

The oldest rocks met with in this area—apart from certain erratic blocks—are a series of sediments ranging from fine-grained slates, through more or less massive mudstones and flagstones, to a type of rock best described as a rather coarse greywacke.* They show everywhere a prevailing greyish-green or green colour, and are of very compact texture, the finer varieties being very strongly cleaved and much slickensided, often with a silky lustre, but never sufficiently crystalline to be called phyllites. The main cleavage lines run in a north and south direction, more or less parallel to the coast (Plate 1, Fig. 1). As seen in the field, the bedding is much obscured by the cleavage, but in places it is clear that the whole series is thrown into anticlines and synclines, the axes of which appear to run in a general N.E.–S.W. or N.–S. direction. In Plate 1, Figs. 2, 3, and 4, the bedding is clearly seen and the folding is also conspicuous. This folding was in all probability produced by pressure from an easterly direction, crumpling and compressing the rocks against the more rigid continental mass to the west. It is also more pronounced towards the south of the area, the anticlines and synclines further north being much shallower than those of Duke of York Island. The folds can be best seen on the north face of this island, but unfortunately no good photograph was here obtained.

The formation was examined along the coast at intervals from the rocky bluff between the George Newnes Glacier and the Murray Glacier northwards to Turret Island beyond the entrance to Robertson Bay. Exposures of rock were numerous, but at only two places was it possible to ascend the cliffs without special climbing equipment. These places were Duke of York Island, and the most southerly bluff of all where the basalt of the Cape Adare volcanic series cuts across the sediments in a dead straight line, with features suggesting a fissure eruption on a small scale. Unfortunately at both these places the rock-exposures were limited to isolated bluffs cut off from the hinterland, in the former case by a glacier, and in the latter by a field of highland ice of considerable extent.

Specimens of rock *in situ* were collected at a considerable number of points, as indicated by crosses on the map (Fig. 8). The most important localities were as follows:—Duke of York Island, Penelope Point, Relay Bay, Islands Point, north side of Birthday Point, Pressure Bay, Cape Barrow, and Turret Island. On examination of specimens and slices it was found that the whole series showed a remarkable degree of uniformity, though in a general way they can be referred to three types:—coarse greywackes, fine greywackes, and well-cleaved slates.

---

* Specimens of some of these rocks, mostly from Duke of York Island, were collected by the "Southern Cross" Antarctic Expedition and have been briefly described by G. T. Prior [Report on the Collections of Natural History made in the Antarctic Regions during the Voyage of the "Southern Cross." London, 1902, p. 325].

PETROGRAPHY OF THE ROCKS. (R.H.R.)

Microscopic examination of thin-sections shows that in the great majority of the specimens the grains rarely exceed ·1 mm. in diameter, and most are finer than this. As a rule the grains in any one layer are very uniform in size, although in the same section there is often considerable variation in this respect from one layer to another. The most striking general characteristic of the rocks as a whole is the extreme angularity of the constituent grains: the significance of this feature is discussed later. The textures of the coarser types are about what in a less consolidated rock would be called a sandstone and none of the specimens found *in situ* are sufficiently coarse to be described as conglomerates.

In all the specimens examined of whatever grade the commonest clastic mineral is quartz. This is obviously derived from two distinct sources; from vein-quartz and from quartzites. In some instances the vein-quartz contains vermicular chlorite.* The quartzite-quartz in some instances is derived from rocks of exceedingly fine texture, and in many specimens small chips and grains of mudstone and slate are common. In the coarser types (greywackes) a small proportion of felspar is almost invariably present, including both orthoclase and plagioclase with a small extinction angle. White mica is very abundant in flakes of all sizes: in the greywackes the larger flakes are certainly original and clastic, but the finer-grained rocks contain a good deal of obviously secondary sericitic mica along cleavage planes. Very rarely flakes of almost fresh biotite are seen, and in some specimens large flakes of chlorite most probably represent detrital biotite. Thus quartz, felspars, and micas, with rock-chips, are the main constituents of the coarser rocks, and it may be inferred that the same applies to the finer types. In none of the numerous thin-sections examined was discovered any of the usual "heavy minerals" or a single mineral grain which could be definitely attributed to rocks that have undergone a high grade of metamorphism, either thermal or dynamic. The rocks are not adapted to examination by crushing methods, owing to their hardness and high degree of cementation.

It is noticeable that in the majority of specimens of the coarser types the edges of the larger grains are not quite sharp: each grain is as a rule very slightly corroded at the edges, as if by reaction with the constituents of the ground-mass, thus indicating a very low grade of metamorphism. This effect is extremely common in the coarser arenaceous sediments in general when somewhat crushed and sheared.

The principal mineral constituents of the finer matrix of the rocks, the cementing material, are, so far as can be determined, quartz, mica, chlorite, and carbonates. It is to the chlorite in the cement that the prevailing green colour is due. Of these constituents the most interesting are the carbonates, which in very many specimens are more or less aggregated into spots, and often markedly so. In some specimens the carbonate is mainly calcite, but it is usually chalybite, with probably some dolomite or ankerite. This abundance of iron carbonate is one of the most noteworthy characters of the rocks, when fresh. In more weathered specimens the chalybite is oxidized and hydrated and gives a still more strongly spotted appearance.

---

* Prior (*loc. cit.*) noted the development of vermicular chlorite near the contact of contorted quartz veins with the equally contorted slates.

The finer-grained rocks are even more monotonous and uniform in character than the coarser-grained greywackes described above, the principal variations here being in the amount of cleavage. The less cleaved varieties may be described briefly as chloritic and rather calcareous mudstones, while the more cleaved slates usually show a large proportion of sericitic mica, which accounts for the appearance of sheared and slickensided surfaces. Some of the finer gritty rocks also show a certain amount of shearing, often confined to particular bands, and along these shear-bands mica is also developed.

A few specimens of slightly aberrant character from various localities are worthy of very brief mention. A rock of unusually light colour from Duke of York Island (713) is a quartzite of very irregular and uneven texture : in some shear planes the distinction between grains and matrix has disappeared and it is difficult to make out how much of the quartz is secondary. Another specimen from Islands Point (844) is best described as a felspathic sandstone with a calcareous cement. The carbonate here is calcite, not chalybite. Another specimen from Turret Island (815) is of almost similar character. Some specimens from Pressure Bay show a pronounced nodular structure, with concentric banding, at first sight very suggestive of fossils, but a careful examination by Mr. H. Woods yielded no definite evidence of organic structure. The rock (890–895) is a fine grit or mudstone and the banding consists of lines and specks of iron oxide, often with a rhombohedral outline and thus obviously derived from crystals of chalybite.

At several localities cubes of pyrites* are found in the slaty rocks in varying quantity, and the rocks are often stained brown by its oxidation products.

The whole of the slate-greywacke formation is permeated by lenticles, veins, and stringers of quartz, associated with chlorite, calcite, dolomite, chalybite, and pyrites (Plate 1, Fig. 5). Careful examination in the field and in the laboratory indicate that these veins are barren of mineral deposits of economic importance, only an occasional small crystal of blende or galena having been observed in them.

The weathered surfaces of these rocks often show a curious type of fretting probably due to wind-action (Plate 1, Fig. 6), and on this pitted surface the quartz veins stand out strongly.

---

* The "Southern Cross" specimens (*loc. cit.* on p. 124) were mainly of this type since they were collected by C. E. Borchgrevink as ore-specimens on account of the iron-pyrites they contained.

PETROGRAPHY OF THE ERRATICS OF SEDIMENTARY ROCKS. (R.H.R.)

The greater part of the erratics seen on the Newnes and Murray Glaciers consisted of rocks of the slate-greywacke formation, most of them in all essential features identical with the types just described. There is, however, one rock from the Newnes Glacier of considerable interest, represented by several specimens, and worthy of a detailed description.

This rock is a conglomerate of remarkably even-grain and variegated appearance. Under the microscope the pebbles (mostly 3 mm., rarely over 4 mm. in diameter) are seen to consist of vein-quartz, quartzite of varying grades, mudstone and greenish slate, quartz-calcite rocks (not markedly schistose), fresh felspar especially plagioclase, and, most interesting of all, brown to red lavas of various kinds showing typically characteristic fine-grained trachytic and orthophyric structures. Most of these volcanic rocks are very fresh. Many of the fragments in the conglomerate are remarkably angular, though some of the larger ones are somewhat rounded. The fine cementing material is mainly of a muddy nature, but includes a good deal of calcite.

Two or three specimens from the Murray Glacier may also be mentioned briefly. One is a micaceous sandstone which contains flakes of fresh biotite and may perhaps be best described as an arkose since it has more felspar than usual. Another is a fine-grained, chloritic, gritty rock, with marked current-bedding clearly brought out by alternating green and cream-coloured or pale-brown bands. It is roughly cleaved at right angles to the bedding, producing a kind of flaggy structure.

A grey, silky-looking, and much crumpled rock shows very numerous pink and white oval spots of chalybite up to about 2 × 1 mm. This rock may perhaps be described as a spotted phyllite and suggests a somewhat higher degree of metamorphism than the other specimens. Removal of the carbonates by boiling with acid increased the general phyllitic and crystalline appearance of a small fragment. Another spotted rock when examined microscopically showed that the spots were rhombohedral crystals of carbonates, with zones apparently containing varying proportions of iron.

EXTENT OF THE SLATE-GREYWACKE FORMATION.

As before stated, specimens of the slate-greywacke formation *in situ* were only obtained at points along the coast of Robertson Bay, but a considerable inland extension of the same rock-types is indicated by the fact that the existing glaciers carry a large amount of débris from this formation, together with blocks of the younger volcanic series and of a granite which has broken through it and which may form the main mass of the mountains behind. Some high-level moraines on Cape Adare carry blocks of schist, a quartzite similar to that of the Beacon Sandstone, a typical dolerite, and a coarse porphyritic gneiss like that found *in situ* in the Terra Nova Bay region and as an erratic at Cape Irizar. This suggests that at the last glacial maximum the ice-streams brought material from beyond the limits of the slate-greywacke outcrop, which we may thus infer is bounded to the west by the basal Archaean complex overlain by the Beacon Sandstone with its dolerite sills. How far inland this boundary may be is unknown.

ORIGIN AND AGE OF THE FORMATION.

From the foregoing descriptions it is obvious that these rocks belong to a typically sedimentary series of very uniform character, the chief variation being in the degree of coarseness of the material, which in its turn has determined the susceptibility or otherwise to cleavage. The rocks are notably well-stratified, sometimes showing false-bedding, and the material is well graded. The general appearance of the rocks, with their prevailing grey and green colours, suggests a considerable age: in fact they present the characteristics usually associated with Palaeozoic or Algonkian sediments. Among British formations their nearest analogue is to be found in the Ingletonian series, to which indeed they show a strong resemblance. If the erratics of conglomerate are assumed to belong to the slate-greywacke formation, the resemblance is still stronger, as this is very like the coarser grit of Chapel-le-Dale, Yorkshire, known commercially as "Ingleton Granite."

Actual definite evidence of age however is scanty. The slate-greywacke rocks certainly look older than the Beacon Sandstone and its underlying shales with Devonian fossils. Hence it would appear to follow that the slate-greywacke series is at least as old as Lower Palaeozoic. The actual mineral composition of the rocks does not afford much help in this direction. It is pretty safe to say that they have not been formed directly from a series of crystalline schists, since the larger included rock-fragments, when identifiable, are mainly quartzites of a low grade of recrystallization and sericitic clay-slates without recognizable metamorphic minerals. In fact they seem to be made up of the débris of another rock-series very like themselves, with a small addition of igneous material possibly volcanic.

The most characteristic secondary minerals are chlorite, carbonates (especially chalybite), and pyrites, which indicate only a mild degree of metamorphism.

As to the origin of these sedimentary deposits, it is clear that, however they were formed, there was little or no rolling action. The extreme angularity of the grains suggests frost-shattering, and the freshness of the felspars is also another important point indicating a minimum of chemical weathering. However, the even-grading of the sediment and the regularity of the bedding are against actual deposition by ice, and this leaves wind only as a possible agent of deposition.

Such extremely angular fragments and clear unweathered felspars as occur in the coarser bands in these sediments can be exactly paralleled in the residual frost and thaw deposits of Cape Adare and Ross Island. The size of the fragments in these localities is equally uniform, though generally greater. This is due to the sifting action of the present-day gales and blizzards which blow all material below a certain size into the sea. The finer texture of these ancient sediments indicates that at the time of their formation the winds of this region were less violent than they are now. The common occurrence of false-bedding presents no difficulty, since it is prevalent in dune-deposits, and is also commonly observed in silt-deposits forming in modern glacier-streams.

These old sediments, therefore, suggest the shoreward phase corresponding to the deposition of sand, silt, and mud in the adjacent seas of the period, and they are also indicative of a climate certainly of dry type and probably cold, approximating somewhat closely to the conditions at present prevailing in the Polar regions.

BRITISH MUSEUM NATURAL HISTORY

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
DUKE STREET, STAMFORD STREET, S.E 1, AND GREAT WINDMILL STREET, W. 1.

PLATE 1.

Fig. 1.—Cleavage-planes in slate-greywacke formation. Turret Island. (p. 124).
Fig. 2.—Syncline in slate-greywacke formation. Coast N. of Robertson Bay. (p. 124).
Fig. 3.—Bedding and fault-planes in slate-greywacke formation. Relay Bay. (p. 124).
Fig. 4.—Cave in slate-greywacke formation. Relay Bay. (p. 124).
Fig. 5.—Quartz veins standing out in weathered greywacke. (p. 125).
Fig. 6.—Fretting of rock produced by wind-weathering. (p. 126).

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BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910.

NATURAL HISTORY REPORT.

GEOLOGY. VOL. I, No. 5. Pp. 131–166.

THE METAMORPHIC ROCKS OF SOUTH VICTORIA LAND.

No. 5a.—THE METAMORPHIC ROCKS OF THE McMURDO SOUND REGION.

BY
W. CAMPBELL SMITH, M.C., M.A., F.G.S.
Fellow of Corpus Christi College, Cambridge. Assistant in the Mineral Department of the British Museum.
AND
F. DEBENHAM, O.B.E., B.A., B.Sc., F.G.S.
Fellow of Gonville and Caius College, Cambridge. Geologist on the Expedition.

No. 5b.—THE METAMORPHIC ROCKS OF THE TERRA NOVA BAY REGION.

BY
W. CAMPBELL SMITH, M.C., M.A., F.G.S.
Fellow of Corpus Christi College, Cambridge. Assistant in the Mineral Department of the British Museum.
AND
R. E. PRIESTLEY, M.C., B.A.
Geologist on the Expedition.

WITH TWO FIGURES IN THE TEXT AND TWO PLATES.

B. M.
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Sold by Longmans, Green & Co., 39, Paternoster Row, E.C. 4; B. Quaritch, Ltd., 11, Grafton Street, New Bond Street, W. 1; Dulau & Co., Ltd., 34-36, Margaret Street, Cavendish Square, W. 1;
and at the
British Museum (Natural History), Cromwell Road, London, S.W. 7.
1921.

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[*Issued 26th November, 1921.*]

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W. CAMPBELL SMITH, M.C., M.A., F.G.S.
Fellow of Corpus Christi College, Cambridge.
Assistant in the Mineral Department of the British Museum.
XVII.
AND
F. DEBENHAM, O.B.E., B.A., B.Sc., F.G.S.
Fellow of Gonville and Caius College, Cambridge.
Geologist on the Expedition.

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W. CAMPBELL SMITH, M.C., M.A., F.G.S.
Fellow of Corpus Christi College, Cambridge.
Assistant in the Mineral Department of the British Museum.
XVI
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R. E. PRIESTLEY, M.C., B.A.
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No. 5a.—THE METAMORPHIC ROCKS OF THE McMURDO SOUND REGION.*

BY
W. CAMPBELL SMITH, M.C., M.A., F.G.S.
Fellow of Corpus Christi College, Cambridge.
Assistant in the Mineral Department of the British Museum.
AND
F. DEBENHAM, O.B.E., B.A., B.Sc., F.G.S.
Fellow of Gonville and Caius College, Cambridge.
Geologist on the Expedition.

INTRODUCTION.

As recorded by H. T. Ferrar, the geologist of the "Discovery" Expedition of 1901–04, the whole of the coast line of South Victoria Land, from Granite Harbour down to the Koettlitz Glacier, consists of a foundation series of metamorphic rocks. While locally, and especially towards the north, these vary to a considerable extent, there is sufficient similarity in their field relationships to allow us to treat them as of common origin and age.

They are particularly strongly developed to the south of New Harbour and less so to the north, but this difference is due largely to the fact that the southern area contains definite foothills with many rock exposures while the northern is comparatively flat and covered with the ice of the Wilson Piedmont. For the northern area, therefore, the only knowledge we have of the rocks is that gained from an examination of the few rocky headlands that jut out from beneath the ice as one proceeds up the coast, and from a study of the erratics. Towards the plateau the land rises so rapidly that the basal rocks are soon hidden beneath the more recent series of igneous and sedimentary rocks, and the farthest west that the metamorphics have been met with is about on the line from hill *m* (6,165 feet)† in the Kukri Hills to a point opposite Suess Glacier in Dry Valley some 20 miles from the coast.

No junction between the later sediments and the metamorphic series has yet been found, so that no opinion can be formed as to the nature of the surface of the latter at any period. To the south of New Harbour the metamorphic rocks are seen forming the tops of hills at 5,000 feet and boulders are found at 4,000 feet, but northwards in the direction of Granite Harbour they are never seen more than 1000 feet above sea-level.

---

* No. 5a has been written by W. Campbell Smith, in collaboration with F. Debenham as regards the field-geology.

† For maps see the one published with "National Antarctic Expedition," 1901–4. Natural History. Vol. 1 (1907); also map facing p. 291 in "Scott's Last Expedition." London, 1913, vol. 2.

Definite contacts between the metamorphic rocks and the intrusive granites are not known, and although exposures in the Kukri Hills and at Cathedral Rocks are probably near the junction nothing very definite can be learnt from them. At nearly all its exposures the granite is seen to contain very frequent inclusions of metamorphic rocks of every kind represented in the district, many of them of considerable size. They have evidently acquired their present characters before the intrusion of the granite and must represent fragments of the foundered roof of metamorphic rocks into which the granite mass was forced.

CRYSTALLINE LIMESTONES.

Crystalline limestones, coarse-grained and generally pure-white in colour, are the most striking of the metamorphic rocks of this region. Although they are seen frequently *in situ* they occur only rarely as erratics, except close to their source, as they crumble with great ease when weathered. They have been recorded and described by Ferrar[*] and Prior[†] from the Northern and Southern Foothills, and, as erratics, from the Koettlitz Glacier.

David and Priestley[‡], and Mawson[§] described them at Cape Bernacchi and Marble Point, and suggested their probable extension north to Dunlop Island where two erratics were found.[‖]

The present expedition has extended our knowledge of these rocks in the Ferrar Glacier region and has recorded them in place on the top of Heald Island in the south, and, as erratics, at Mount Suess, 90 miles north of Heald Island. There are indications that they may extend farther north to the Terra Nova Bay region.

At Heald Island the limestones are 800 feet thick and strike a little west of north with a steep dip. Débris prevents any sequence being made out, but gneisses and schists appear to be *in situ* close by.

At Salmon Hill,[**] north of Davis Glacier in the Southern Foothills, the whole hill is formed of massive, grey, pink-weathering limestone seamed with bands, probably dykes, of a dark rock, all trending in a north-easterly direction.[††] The strike of the limestone is somewhat west of north and the beds on the north-east face of the hill are dipping north-east at from 50° to 70°. The limestone was estimated at from 4,000 to 6,000 feet thick, and is believed to be at a different horizon from that exposed at Heald Island.

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[*] Ferrar (H. T.). National Antarctic Expedition, 1901–4. Natural History. Vol. 1 (1907). pp. 25–29.

[†] Prior (G. T.). ,, ,, ,, ,, ,, ,, p. 124.

[‡] David (T. W. E.) and Priestley (R. E.). British Antarctic Expedition, 1907–9. Geology. Vol. 1 (1914), p. 233.

[§] Mawson (D.). Brit. Ant. Exp., 1907–9. Geology. Vol. 2 (1916), p. 231.

[‖] Skeats (E. W.). ,, ,, ,, ,, ,, ,, p. 195.

[**] See Fig. 2, p. 106, in No. 4 of this volume.

[††] Similar dark veins are recorded at Hill G4 by Ferrar, where the rock is allied to banakite. Ferrar (H. T.). *Loc. cit.*, p. 27. Prior (G. T.). *Ibid.*, p. 133.

At Cape Bernacchi two or three distinct beds of limestone, varying in thickness from 50 to 200 feet, are seen flanked by schists and gneisses, striking north-north-west, and dipping at about 30° west. David and Priestley,* however, recorded a dip of 15° N. at the point itself, but noted that the beds here are very contorted.

The limestones mentioned hitherto are all white saccharoidal with grains varying from 2 mm. to 1 mm., and occasionally showing pale-grey bands: they are usually very free from impurities, but graphite, brown mica, and, more rarely, diopside occur both at Salmon Hill and at Cape Bernacchi.

Farther west in the Kukri Hills limestone was recorded by Ferrar below hill *m* (6,165 feet), dipping north-east at 70° and striking north-west, with an apparent thickness of 1,000 feet. Here it abuts on a grey "augen-gneiss" but the junction was not seen by Ferrar. The limestone collected by Ferrar is white, of medium-grain, and contains a little graphite and a pale-yellow mica. The limestone beds appear again outcropping on the other side of the Kukri Hills opposite where the Suess Glacier reaches Dry Valley. Here the geologists of the present expedition recorded several beds, one 100 feet thick, dipping almost vertically and lying between an "augen-gneiss" on the east and schists on the west. At this last exposure specimens (D12F) of two kinds of limestone were collected, both remarkable in that they contain chondrodite or clinohumite.

One is palest-grey, 1·5 mm. in grain, and consists mainly of calcite, with many specks of graphite, a few small flakes of a pale-brown mica, prisms of tremolite in small patches, and pale-yellow grains of a mineral of the chondrodite group which shows twin lamellæ and is probably clinohumite.

The other is a pure-white crystalline limestone similar in grain to the above, but containing bands rich in dark-brown chondrodite and violet-grey spinel in octahedra up to 2 mm. across (Pl. 1, Fig. 3). Parts of this rock also contain abundant grains of a pale-yellow mineral probably clinohumite. The other minerals present are a very pale brown mica and apatite. Staining tests show that there is a considerable proportion of dolomite present but the carbonate in the neighbourhood of the chondrodite is mainly calcite. Some specimens show the chondrodite and clinohumite converted into brown and green serpentine. The chondrodite sometimes shows crystal outlines, the crystals reaching a diameter of 3 mm. The pleochroism is very marked, but some golden-yellow chondrodite crystals show patches quite devoid of colour though still in crystalline continuity with the yellow portion. These patches are identical in character with the colourless grains referred to clinohumite. Similar intergrowths of two species have been described, since these notes were written, in the chondrodite-limestones of Marble Delta, Natal.† The chondrodite in the specimens described by Prior ‡ is pale-yellow in the hand-specimen, quite colourless in thin-section, and corresponds with the mineral here referred to clinohumite.

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* David and Priestley. *Loc. cit.*, p. 233.

† Du Toit (A. L.). Quart. Journ. Geol. Soc., 1919, vol. 75, p. 130.

‡ Prior (G. T.). Nat. Ant. Exp., 1901–4. Natural History. Vol. 1 (1907), p. 124.

An erratic of compact white limestone (D27F), collected in Dry Valley below the Riegel, contains small patches of chondrodite and clinohumite but no spinel.

Chondrodite-limestones occur again in the moraine at the north end of Gondola Ridge, Mount Suess, 45 miles to the north,* where five erratics (D83G) were collected. All five contain minerals of the chondrodite group or their brown and green serpentinization products. Spinel was observed in one section only. The green serpentine in these rocks differs in character from the brown and shows no traces of the mineral from which it was derived. The brown serpentine, on the other hand, frequently encloses relics of clinohumite. It is pale-yellow in thin-section and is made up of small fibres of low birefringence, positive elongation, and refractive index near 1·55: it encloses fibres of actinolite? and colourless crystals too thin to give any definite optical characters. It contains only a little iron and no alumina.

Reference has already been made to inclusions of metamorphic rocks in the grey granite of Granite Harbour. Among these there are two large masses of limestone. One, known as "Marble Dyke," on the Flatiron north of the bay, is 50–60 feet thick and strikes north-north-west. The other outcrop, on the south of the bay, 1½ miles west of Cape Geology, is 100 feet thick, with an apparent strike slightly east of north. At "Marble Dyke" the limestone is bounded on both sides by a thin selvage of rocks described in the field as "schists." Both masses show at their edges the effects of contact metamorphism which will be described in No. 6 of this volume, but the central parts are not sensibly affected and probably represent fairly well the nature of the limestone before its inclusion in the grey granite. The specimens collected (D16G) show that the limestones of these included masses are quite similar to those already described from Salmon Hill and Cape Bernacchi. A pale chondrodite occurs sparingly with graphite in thin bands in one specimen. Other specimens contain thin bands rich in tremolite, and grains of diopside (0·1 mm.) are found occasionally. One specimen from "Marble Dyke" (D44G) seems to differ from any others seen. It is a compact white limestone, with rather indefinite pale-greenish bands which stand out in relief on weathered surfaces. The white parts consist of millimetre-grains of carbonate, apparently all dolomite, with very rare round grains of diopside (0·1 mm.). The green bands are rich in pale-green serpentine associated with a colourless mineral, believed to be forsterite, occurring as irregular broken crystals. The bulk of the carbonate in the green bands is calcite, which presents idiomorphic outlines towards the serpentine. The identification of the colourless crystals as forsterite is doubtful, as the discrimination of this mineral from humite or clinohumite is very difficult and it seems by no means certain that the greenish colour or the nature of the serpentine is distinctive.† The above description of these included masses clearly shows that the crystalline limestones, including the chondrodite-limestones, were in their present condition before the intrusion of the grey granite. The limestones seem to contain highly dolomitic bands which, under certain conditions of metamorphism, have given rise to tremolite and calcite ; while, under certain other conditions, presumably those of contact metamorphism with fluorine present, chondrodite-minerals and spinel have resulted. Ferrar recorded the limestone on the south of the Kukri Hills as abutting against an "augen-gneiss." A similar gneiss is in close proximity to the chondrodite-limestone in Dry Valley. We shall describe this gneiss below (p. 142) and shall show that there are some indications that it was intruded after the limestones and other sediments had undergone the intense metamorphism which converted them into crystalline limestones, schists, and paragneisses. It is probably to the intrusion of this gneiss that the production of the chondrodite is to be attributed.

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* *See* Map, Fig. 16, p. 96, in No. 3 of this volume.

† *See* Du Toit (A. L.). *Loc. cit.*, p. 130.

PYROXENE-GRANULITES.

(PARA-DIOPSIDE-GRANULITES).

Before proceeding to describe the schists and gneisses found in place in the McMurdo Sound area we must notice certain occurrences of compact, hard, green rocks, found as erratics at Cape Royds by the Expedition of 1907–9, and described by Walkom as pyroxene-granulites.* These rocks have nowhere been seen in place except as inclusions in the grey granite of Granite Harbour or as selvages to the included masses of limestone mentioned above. That they are not confined to the area of the grey granite seems to be indicated, however, by their discovery as erratics by Priestley on his journey down the coast. They were found at Tripp Island, Gneiss Point, Marble Point, and Cape Bernacchi, and one specimen (D36G) was collected by Debenham *in situ* at Marble Point. During the Expedition of 1901–4 Ferrar collected an erratic (584) in the east fork of the Ferrar Glacier but no description was published.

Walkom gave detailed descriptions of fifteen erratics of these rocks which he grouped for convenience into acid, basic, and scapolite-bearing pyroxene-granulites. Though composed of a few minerals showing very constant characteristics, the relative proportions of these constituents are extremely variable. There is probably complete gradation from types rich in quartz to other types quite free from it. We shall here describe only those types which differ markedly from any of Walkom's specimens.

Priestley's collection contains only two specimens of Walkom's "acid" class, one (2077) resembling closely Walkom's P. 260,† the other (2109), very rich in quartz and with the pyroxene in very small grains (0·05 mm.), showing clear indications of its sedimentary origin. The quartz grains vary in diameter from 0·1 to 0·2 mm. and are arranged parallel to the planes of foliation, as are also the pyroxene crystals. The rock contains thin layers rich in biotite, which become gradually more and more frequent, so that there is a gradual passage to a biotite-granulite or biotite-schist.

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* Walkom (A. B.). Brit. Ant. Exp., 1907–9. Geology. Vol. 2 (1916), pp. 161–168.

† Walkom (A. B.). *Loc. cit.*, Pl. 1, Fig. 1.

Typical scapolite-bearing examples are not represented, and indeed in Priestley's specimens scapolite occurs only under exceptional circumstances where a band of pyroxene-granulite is in contact with a biotite-granulite described below (p. 139).

Six specimens collected at Marble Point and Cape Bernacchi (2050, 2099, 2101, 2105, 2117, 2138) and one from Gneiss Point (2036) possess the general characters of Walkom's "basic" class containing no quartz. They contain very variable amounts of pyroxene In one case this mineral forms the bulk of the rock, which is traversed by one or two felspathic veins; in other specimens its proportion varies from 25 to 50 per cent. In the felspar the highest extinction angle observed was 26°, corresponding to andesine-labradorite. Sphene is always present as irregular grains or spindle-shaped crystals. Apatite sometimes occurs as small needles in the felspar. All these rocks are yellowish-green in colour. Those composed mainly of pyroxene are granular and have a rough fracture; types richer in felspar are compact and their fracture is smooth. The grain-size varies from 0·2 mm. to 0·6 mm., being coarsest in the pyroxene-rich types. The texture of all is granulitic.

At the same localities and probably weathered out of the limestones were found two dark-green nodular masses with granulitic texture (2048, 2100), consisting almost entirely of pyroxene and sometimes containing pyrites in crystals 4 mm. in diameter. The pyroxene gives extinction $\gamma : c = 47^\circ$. In thin-section it appears pale-green, sometimes quite colourless in the centres of the crystals which often contain inclusions of graphite. It is associated with a little basic felspar, accessory apatite, and dark-brown sphene, with varying amounts of calcite filling cracks and interstices. One specimen (D35F) is very rich in calcite, which forms a matrix for the pyroxene grains.

One dark-green specimen, a small pebble from Tripp Island (2078), shows some black bands and is strongly magnetic. Under the microscope the dark-green bands are seen to consist of colourless pyroxene ($\gamma : c = 36^\circ$—41°) with labradorite, and accessory sphene and magnetite, while the black bands consist of pyroxene with very little felspar, accessory sphene, and rare apatite, in a matrix of magnetite.

A small specimen (2049) from Marble Point, more compact and showing indefinite patches of red-brown garnet, must be very near the eclogites in composition, but shows important differences in that it has a high content of calcite and abundant sphene. The pyroxene is pale-blue-green in thin-section. There are occasional patches of basic felspar and traces of magnetite. Calcite moulds the garnet and fills the interstices between separate grains. The specimen evidently occurred in contact with crystalline limestone as traces of this can be seen on one edge.

From the talus below Double Curtain Glacier, near the south-east end of the Kukri Hills, comes a pale-grey-green rock (D5F) of very variable grain which is probably closely connected with the pyroxene-granulites and crystalline limestones. It consists mainly of colourless pyroxene intergrown with a pale-greenish amphibole, and parts of the rock resemble the tremolite-gneiss (C.R. 440) described by Walkom among the Cape Royds erratics.*

Other rocks which seem to have close relationship with the pyroxene-granulites are the purple hornblendic biotite-schists and biotite-granulites, erratics of which were collected by Priestley between Gneiss Point and Spike Point on his journey down the coast. They are rich in plagioclase, and with the very abundant chestnut biotite there is associated always green hornblende and usually also colourless pyroxene. It may be rocks of this kind to which Mawson alludes as having apparently originated from calcareous slates and sandstones.† An example (2109) was mentioned above of an acid pyroxene-granulite passing quite gradually into one of these biotite-granulites. In another specimen (2030) a biotite-schist contains what seems to be part of a nodule consisting of calcite with quartz, felspar, pyroxene, and sphene, and separated from the biotite-schists by a thin band of pyroxene-granulite of very fine grain (0·1 mm.). In another case a biotite-granulite (2043) is seen in contact with a scapolite-bearing pyroxene-granulite in which the scapolite is developed in large plates enclosing the other constituents. Where the one rock merges into the other the pyroxene-granulite becomes very indefinite in character and the junction is quite irregular not following closely the planes of foliation. The biotite-granulite consists of quartz, andesine, brown biotite, and green hornblende, the last two in intimate association. Apatite and sphene are abundant. Colourless pyroxene is always present but bands rich in this constituent seem to get more frequent as the pyroxene-granulite is appproached.

The area over which the erratics of the pyroxene-granulites have been found coincides in general with that occupied by the metamorphic series in which crystalline limestones are known to be well developed. Many of the granulites show very close resemblances to the "gneiss à pyroxène" of Brittany, Waldviertel, and Sweden described by Lacroix,‡ which are always associated with crystalline schists and almost always with crystalline limestones; while the specimens richest in pyroxene compare closely with the diopside-rock described by Tilley§ as associated with the Pre-Cambrian dolomites of the Hutchison series in Southern Eyre Peninsula, South Australia, and definitely attributed by him to the metamorphism of impure dolomitic sediments.

Pyroxene-granulites quite similar to the above will be further discussed in No. 5b of this report which deals with the metamorphic rocks of the Terra Nova Bay region.

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* Walkom (A. B.). Brit. Ant. Exp., 1907–9. Geology. Vol. 2 (1916), p. 183.

† Mawson (D.). *Ibid.*, p. 232.

‡ Lacroix (A.). Bull. Soc. franç. Min., 1889, vol. 12, pp. 83 *et seq.*

§ Tilley (C. E.). Geol. Mag., 1920, vol. 57, p. 492.

CRYSTALLINE SCHISTS.

The crystalline schists vary considerably in character in different parts of the district. The most extensive outcrop seen was that on Heald Island. The slopes were so covered with débris that it was impossible to get any measurements of their thickness but it is probably of the order of 2,000 feet. The abundance of fragments of schists which were seen in the lateral moraines of the Koettlitz Glacier is additional evidence of extensive outcrops of these rocks in the vicinity. In character they were seen to vary from coarse biotite-schists to hard bands with little evidence of fissility. The specimens (D2K) collected from this locality are all of one type, a muscovite-schist rich in graphite and with abundant pseudomorphs probably of andalusite. These were collected *in situ* at the top of the island. The rock is pale-greyish-violet with patches and streaks of brown, and with bands crowded with long thin bodies (1·4 cm. × 1·5 mm.) consisting of pale-green mica. The grain is even and averages 0·1 mm. The main constituents are quartz with subordinate felspar (albite), muscovite, and very pale pinkish-brown biotite. Minor constituents are graphite, in rods and grains, short prisms of colourless tourmaline, and rather rounded crystals of rutile; all three are present in remarkable abundance (Pl. 1, Fig. 2). A greenish-yellow turbid mineral with granular appearance has not been identified. The green mica of the pseudomorphs has an optic axial angle of about 60°. No trace of the original mineral remains, but it is highly probable that it was andalusite.

It does not appear that there are any large occurrences of schist between Heald Island and the south of the Ferrar Glacier, but there is evidence that there are many outcrops of these rocks in the Kukri Hills. Schists of various kinds were abundant in the débris on the sides of this line of hills, and on the summit towards the eastern end of the range there are a series of beds, dipping nearly vertically, which were classed in the field as "calc-schists." Their extent is hidden by snow and rock-débris and no specimens of them were brought back. Schists were also seen in abundance in the moraines of the Lower Ferrar Glacier and are probably developed on both sides of the valley.

In Dry Valley, opposite Suess Glacier, rocks classed as schists in the field are bedded with the crystalline limestones, have a thickness of about 500 feet, and are dipping almost vertically. Some of these had all the appearance of slates. The frost has weathered them into veritable "penitentes," and the weathered "biscuit" is scattered over so large an area that there is a tendency for the extent of the outcrop to be much over-estimated.

The only specimens actually collected at this outcrop were from immediately west of the crystalline limestones opposite Suess Glacier. These were of two types, a medium-grained garnetiferous sillimanite-gneiss, and a much finer-grained and very fissile cordierite-bearing garnet-gneiss.

The garnet-sillimanite-gneiss (D14F) is mainly made up of dark-red garnet and grey fibres of sillimanite (Pl. 1, Fig. 4). The garnets, pale-pink in thin-section, are crowded with inclusions of graphite, biotite, sillimanite, and quartz. They are closely wrapped round by masses of sillimanite which is developed in remarkable abundance, both as needles and as well-formed prisms sometimes 0·25 mm. thick. Between the sillimanite appear fine-grained (0·12 mm.) patches of quartz and subordinate orthoclase and oligoclase, all in rounded grains, with brown biotite in very small flakes packed between the quartz grains. Graphite is abundant, and apatite is an important accessory occurring in large groups of crystals. The sillimanite imparts a slightly schistose structure to the rock.

The cordierite-bearing garnet-gneiss (D9F) is a fine-grained, purple, foliated rock showing pink garnets, up to 2 mm. in diameter, and abundant brown biotite. There are frequent white felspathic patches, coarser in grain than the rest of the rock and parallel to the foliation. The rock tends to split into laminæ (1–2 mm. thick) parallel to the foliation. The finer-grained purple parts show garnets, colourless in thin-section, free from inclusions, and presenting rounded outlines, in a groundmass of quartz and subordinate oligoclase, abundant brown biotite in small flakes (0·05 mm.), quite subordinate cordierite, and occasional small bunches of very small needles of sillimanite (Pl. 1, Fig. 1). The only accessory constituent observed is pyrites. The texture is lepidoblastic. The quartz is even-grained (0·25 mm.) and shows well-developed mortar-structure. In the coarser-grained parts of the rock some of the grains are 0·6 mm. in diameter and lie in a fine-grained matrix of quartz and biotite. In this part of the rock cordierite seems to be absent.

These rocks, both from their composition and their position with regard to the limestone, may be regarded with certainty as metamorphosed argillaceous sediments. In (D9F) there is evidence of later "epi-metamorphism" superimposed on the more intense metamorphism which produced the cordierite.

Both along the Koettlitz and in the New Harbour region there are many small patches of very dark schists which are not evenly-bedded and are frequently in lenticular patches. It seems probable on field relations alone that these represent basic dykes which have suffered in the general regional metamorphism. These rocks are still more clearly seen at Cape Bernacchi and Marble Point, where they differ very noticeably from the other metamorphic rocks. Specimens of two types were collected in Dry Valley. One (D13F) from the talus slopes on the north side of Dry Valley below Suess Glacier is a biotite-amphibolite consisting mainly of pale-green hornblende often surrounding brown biotite which it appears to be replacing : andesine is present in small amount. The other (D32F), collected from the talus below the Riegel, is a hornblende-schist with a little felspar (andesine) and rare biotite.

At Cape Roberts, Priestley collected a dark fine-grained (0·4 mm.) biotite-amphibolite (2067) consisting of about 50 per cent. dull-green hornblende with brown biotite and andesine, some quartz, and abundant small apatites.

Other amphibolites (2034, 2035) from Gneiss Point, somewhat similar to the above in grain, are rich in sphene. They resemble the sphene-bearing amphibolite described by Mawson from the Ferrar Glacier moraines.* Several rather similar rocks were collected, and this series shows gradations to the sphene-bearing diorites of Mount Larsen,† which, as Mawson has pointed out, are not normal diorites but are suggestive of lamprophyric segregations.

Associated with the schists at some localities were rocks noted at the time as quartzites, but their relations to the other beds were nowhere evident, and those collected seem to represent altered acid intrusions of slightly younger age than the schists with which they occur.

GNEISSES.

The study of the gneisses in the field has not led to any clear conception of their extent or their relations to the other rocks. In a general way they have been separated from the truly schistose rocks, but it was much more difficult to distinguish them from the foliated rocks seen at Cape Roberts and at other points along the coast, which at these places present the characters of true gneisses but elsewhere are seen to grade into the grey granite of Granite Harbour with its abundant inclusions of metamorphic rocks.

Gneisses, probably intruded by younger granites, are strongly developed on Heald Island. Ferrar had already recorded them on the northern slope of the Northern Foothills and as forming the greater part of the Kukri Hills to the east of hill *m*.

The rock from immediately east of the crystalline limestones in Dry Valley, opposite Suess Glacier, compares very closely with the grey "augen-gneiss" (727) described by Ferrar ‡ and Prior § as forming the foot of D4 (Sentinel Peak) and adjoining the crystalline limestone at the base of hill *m* on the southern side of the Kukri Hills. It is a finely foliated biotite-bearing hornblende-gneiss, sometimes showing eyes of orthoclase. Green hornblende is the dominant ferro-magnesian constituent but is always associated with brown biotite. Quartz is present in greater amount than the felspars. The grains, which average 0·5 mm., are all more or less rounded, and it is noteworthy that *cataclastic* structure is very well developed. This gneiss probably represents a granitic intrusion, but its exact relation to the limestones is not known. It does not show evidence of such a high degree of metamorphism as that which the limestone and associated cordierite- and sillimanite-bearing rocks have clearly suffered. This suggests that it was intruded after these sediments had been converted into crystalline limestones and schists.

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* Mawson (D.). Brit. Ant. Exp., 1907–9. Geology. Vol. 2 (1916), p. 226.

† Mawson (D.). *Loc. cit.*, pp. 224–226.

‡ Ferrar (H. T.). Nat. Ant. Exp., 1901–4. Natural History. Vol. 1, (1907), p. 30.

§ Prior (G. T.). *Ibid.*, p. 125.

A fragment (D32F) of this porphyritic gneiss was found farther west in the talus below the Riegel in Dry Valley.

Fragments (D18F) collected in the talus on the north side of Dry Valley, near Cheyenne Crater, are of fine-grained (0·5 mm.) granulitic biotite-hornblende-gneiss very similar to the hornblende-gneiss described by Prior from Cathedral Rocks (724).* These are probably inclusions in the granite.

Fine-grained, well-foliated, biotite-gneiss (D5F) occurs as fragments at the base of Double Curtain Glacier.

Priestley's collection includes several fine-grained (1–2 mm.) granulitic biotite-gneisses, very rich in biotite, from Dunlop Island and Marble Point. Another type, found at the same localities and also at Gneiss Point, is a dark-brown gneiss with very abundant biotite, and some pale-green hornblende. The felspar in these rocks is andesine, and the rock may be described as a hornblendic biotite-plagioclase-gneiss. These rocks are fine-grained (0·3–0·4 mm.) and show marked foliation.

It only remains to mention a group of medium-grained, pale-grey rocks, often with brown stains, which are classified as pyroxene-gneiss and pyroxene-bearing aplites. These rocks occur as erratics at Cape Bernacchi and Marble Point. The pyroxene-gneisses contain sphene and large crystals of colourless pyroxene in a groundmass of quartz and orthoclase, with subordinate oligoclase. Myrmekite is well developed. The aplites consist of quartz, orthoclase, and albite-oligoclase, and contain occasional crystals of sphene and colourless pyroxene. There seems every gradation from the pyroxene-gneiss to aplites almost entirely free from either pyroxene or sphene. The texture is granulitic and the grain-size varies from 0·5 mm. to 1·5 mm.

Several of the specimens show contacts between the aplites and the purple biotite-granulites. The examination of several thin-sections seems to indicate that the pyroxene and sphene are being produced in the aplites as a result of these contacts, and there is some evidence that pyroxene-rich bands in the biotite-granulite are more frequent near the contact with the aplite. It is possible that the pyroxene-gneiss is the result of endomorphic changes induced in aplitic dykes near their contacts with some of the metamorphosed sediments. Scapolite was only observed along the contact in one case where the aplite was in contact with a pyroxenic calcareous rock of rather indefinite character.

These aplites show evidence of having undergone dynamic metamorphism after their intrusion, and are possibly of much earlier date than the grey granite of Granite Harbour. It is conceivable that they were associated with the intrusions which gave rise to the biotite-hornblende-gneisses of the Kukri Hills.

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* Prior. (G. T.). Nat. Ant. Exp., 1901–4. Natural History. Vol. 1 (1907), p. 125.

CONCLUSIONS.

We have endeavoured to indicate the general nature of the metamorphic rocks which in the McMurdo Sound area form the foundation of the rest of the mainland. They comprise a considerable thickness of schists and crystalline limestones, probably associated with pyroxene-granulites; and represent metamorphosed argillaceous, calcareous, and dolomitic sediments. In addition to this sedimentary series there is an intrusion, probably quite considerable, of biotite-hornblende-gneiss and some amphibolites and hornblende-schists probably representing altered dyke-rocks. The intrusive gneiss is possibly of later date than the metamorphism of the sediments themselves and may be responsible for the development in these of contact metamorphic effects, e.g., production of chondrodite. Beyond this suggestion of the time relation of the gneiss to the limestones it has not been possible to establish any divisions within the metamorphic series.

David and Priestley[*] believed the metamorphic rocks seen by them to be Pre-Cambrian in age, since the Cambrian limestone of the Beardmore Glacier with *Archæocyathus* is quite unmetamorphosed and is therefore presumably younger than the crystalline limestones. The geologists of the present expedition returned fully convinced of the truth of this view, for while they had obtained no fresh stratigraphical evidence they had acquired a comprehensive view of the rocks of the whole series which was not without its value. Already it has been pointed out that there are close similarities between the para-pyroxene-granulites of this region and rocks occurring in the Pre-Cambrian of Brittany and elsewhere. If we are right in assuming that the para-pyroxene-granulites, known hitherto only as erratics, are actually associated with the crystalline limestones, then we have in this metamorphic series an association of crystalline limestone, pyroxene-granulite, and garnetiferous sillimanite- and cordierite-gneiss similar to that known to exist in certain series of Pre-Cambrian rocks in many parts of the world, for instance in Burma, Ceylon, Madagascar, East Africa, and South Australia. With the rocks of the last named area, the comparison is a remarkably close one, and the papers recently published by C. E. Tilley[†] on the Pre-Cambrian rocks of the Southern Eyre Peninsula, South Australia, show that in the Hutchison series, the oldest group in that area, there is just that association of rocks which we believe exists in the southern part of the McMurdo Sound region. Mr. Tilley has kindly allowed us to examine his specimens and we find that not only is there this general similarity of the two series, but also many of the individual types of rocks from McMurdo Sound can be matched in the Southern Eyre Peninsula. So close, indeed, is the resemblance that we can confidently presume that the two series are of the same age.

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[*] David (T. W. E.) and Priestley (R. E.). Brit. Ant. Exp., 1907–9. Geology. Vol. 1 (1914), p. 234.

[†] Tilley, (C. E.). Geol. Mag., 1920, vol. 57, pp. 449–492, and 1921, vol. 58, p. 251.

No. 5b.—THE METAMORPHIC ROCKS OF THE TERRA NOVA BAY REGION.*

BY

W. CAMPBELL SMITH, M.C., M.A., F.G.S.

Fellow of Corpus Christi College, Cambridge.
Assistant in the Mineral Department of the British Museum.

AND

RAYMOND E. PRIESTLEY, M.C., B.A.

Geologist on the Expedition.

INTRODUCTION. (R.E.P.)

THE field-notes of this and succeeding parts dealing with the Terra Nova Bay region are the result of investigations extending over the period from January 8th to February 18th, 1912. The "Northern Party" was landed at Evans Coves (Inexpressible Island) on the former date with instructions to restrict its activities to the country eastward of a line drawn from the position of landing at the seaward end of the Hell's Gate moraine † to the north-eastern extremity of the Nansen Foothills. The geographical and geological survey of the region west of this line was to be undertaken by the "Western Party" of the Expedition after the "Terra Nova" had picked them up at Granite Harbour in January and had transported them north. It is a matter of Antarctic history that, owing to unfavourable ice conditions this programme was not carried out. Had it been possible to foresee the partial failure of the "Terra Nova's" summer campaign in Antarctic waters, the work of the "Northern Party" might advantageously have been carried farther to the west where, as it happened, the most interesting portion of the two districts lay, close to the dividing line already mentioned.

The itinerary of the party during this six weeks sledging was much restricted by heavy snowfall combined with calms and light weather which prevented the quick removal of the snow. For the same reason many exposures were hidden altogether for days at a time and the observations and collections suffered accordingly. Nothing at all could have been done without the cordial cooperation of the whole party, for

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* No. 5b has been written by W. Campbell Smith, in collaboration with R. E. Priestley as regards the field-geology.

† This moraine is the one immediately north of Inexpressible Island, as shown but not named on the map (Fig. 1, p. 146).

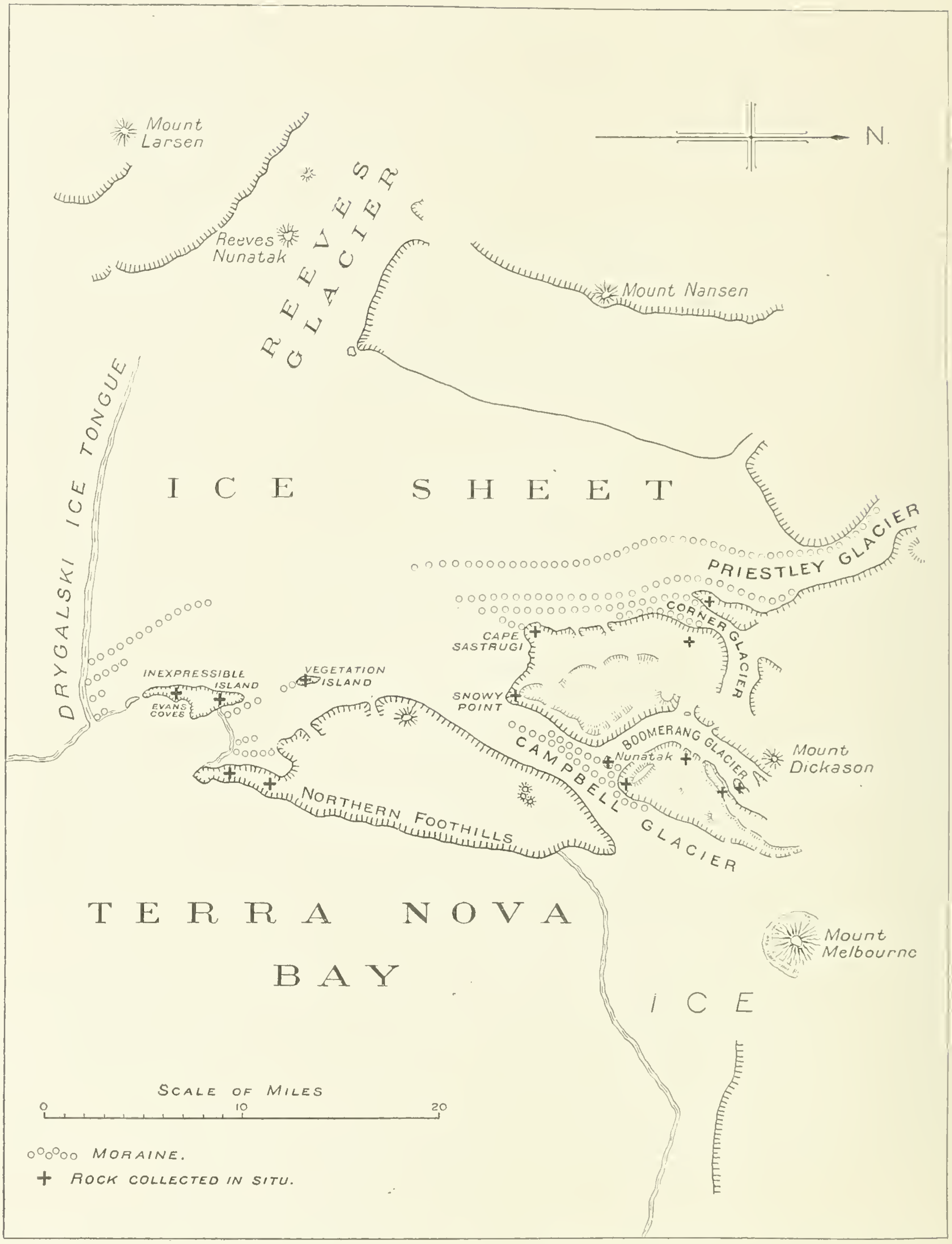

FIG. 1.—Map of the Terra Nova Bay region.

most of the travelling was over glaciers many portions of which were traversed by a network of crevasses. With the whole glacier surface covered with from 12 to 15 inches of loose snow which hid both crevasses and minor irregularities of surface, all collecting and exploration in the earlier days of the journey had to be done by parties of three or more roped together.

The data upon which the map of the area (Fig. 1, p. 146) is based are from the theodolite survey made by Commander Campbell, the leader of the sledge-party. Details beyond those shown in the map illustrating the paper on the experiences of the Northern Party published in the Geographical Journal for January 1914* are added from sketches and notes in the writer's own diary. It is unfortunate in the extreme that during the War one geological field-book was mislaid and has not yet been recovered.†

ROCKS FOUND *IN SITU.*

Metamorphic rocks, some at any rate of which are probably closely allied to the rocks already reported from the Ferrar Glacier region by H. T. Ferrar of the "Discovery" Expedition of 1901–04 and by the geologists of the Shackleton Expedition of 1907–09, were observed *in situ* in several exposures.

Similar rocks also formed no small proportion of the erratics of several of the moraines which, under the circumstances of a short and hurried survey, necessarily provided the great bulk of the rock specimens secured.

Before dealing with these erratics we shall proceed to describe the rocks found *in situ* at each of the five localities (a–e) where they were exposed.

(a) Pyramidal nunatak at the entrance to the Boomerang Glacier, a tributary of the Campbell Glacier.

This isolated hill consists entirely of metamorphic rocks, a fine-grained biotite-gneiss overlying a coarse grey gneiss with occasional large white felspars. The latter appears to be a comparatively slightly metamorphosed granite. It is represented by specimen 1493 and is quite similar to the rock occurring so conspicuously on the east wall of the Corner Glacier. Its characters will be further described below (p. 150).

The upper gneiss is a dark garnetiferous biotite-gneiss varying in texture from granular (1495) to porphyritic (1494), with andesine phenocrysts up to 1·5 cm. long and garnets 0·7 cm. in diameter. In the porphyritic variety, the rock is rich in phenocrysts ("dosemic"). One specimen shows what seems to be a contact with a garnet-schist (like 1637, p. 152). These gneisses consist of quartz, biotite (chestnut to light-buff),* and andesine, with subordinate orthoclase ; minor constituents are zircon and âpatite, and small purple-red garnets, colourless in thin-section and averaging 2 mm. in diameter. Pale-green muscovite is seen in some specimens. Myrmekite is developed in a very beautiful manner in the more highly foliated examples, and intergrowths of quartz and biotite are also well seen (Pl. 1, Fig. 5).

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* Priestley (R. E.). Geographical Journal, 1914, vol. 43, No. 1, pp. 1–16, with map.

† For a general description of the region explored the reader is referred to the Physiographic Memoir of the Expedition. Observations made on the land- and sea-ice will be found in the volume on Glaciology.

These garnetiferous biotite-gneisses were only found at two other localities. Two specimens (1315, 1319) were found in one of the moraines of the Priestley Glacier, and a third was collected at Hell's Gate moraine. They were not found in the moraines of the Boomerang Glacier and, as they are rather conspicuous rocks, we may regard this as a fair indication that they are not exposed to the N.E. of the nunatak.

The only other metamorphic rocks collected at the nunatak were a sillimanite-bearing, muscovite-biotite-schist (1505), and several pieces of a pyroxene-pegmatite recalling in external appearance the pyroxene-bearing acid intrusions in the limestone inclusions of Granite Harbour.

The garnetiferous biotite-gneiss and the porphyritic biotite-gneiss were also present in the moraine from the south wall of the Boomerang Glacier, and there is every possibility that structurally the isolated nunatak is a part of the larger *massif* of metamorphic rocks. At these localities the main foliation planes of the gneiss run N.N.E. and S.S.W. and dip W.N.W. at about 60°.

(b) Snowy Point, the extreme south point of the west wall of the Campbell Glacier. This was deeply covered in the usual mantle, composed mainly of locally accumulated frost-weathered fragments with a sprinkling of erratics, in which specimens of mica-schist, quartz-schist, hornblende-schist, and garnet-schist were most common high up the hill. On the lower slopes a biotite-gneiss similar to that found on the Boomerang nunatak was much more common, and it is most probable that this rock occurs *in situ* here. At only one spot was rock undoubtedly *in situ* exposed, and the rock there was a fine-grained schist. Only a few feet could be seen exposed, but the rocks appeared to strike S.E. and N.W. with a steep dip to the N.E.

No specimens of the schist seen *in situ* were brought back, nor are there any specimens of the other schists from this locality. Among the erratics collected on the Point is a banded crystalline limestone very rich in diopside and scapolite and quite unlike any rock seen elsewhere in the district (see p. 158).

(c) A much larger exposure of the metamorphic series was met with at Cape Sastrugi, the south-western extremity of the bluff between the Priestley and Campbell Glaciers, which is another buttress of the trapezoid-shaped *massif* already examined at two of its four corners (Fig. 1).

The Cape is formed of more resistant rocks than those forming Snowy Point and is therefore considerably steeper and much less encumbered with débris. The rocks composing it are a somewhat massive series of quartz-schists, more or less micaceous; and many of them are of a more gneissic texture and with abundant bands, lenticles, and stringers of coarse quartz and quartzite (1679, 1680). A tourmaline-bearing pegmatite is prominent here and will be described with the associated granites in No. 6 of this volume. The schists were dipping due north at an angle of approximately 20°. Amongst the erratics, which were distributed sparsely wherever the Cape was not too steep to bear them, were numerous specimens of gneisses and schists, one of the gneisses (1676) closely resembing the finely banded, black, granulitic gneiss (1901) found *in situ* in the eastern wall of the Corner Glacier and described below (p. 150).

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* Names of colours used are taken from "Color Standards and Color Nomenclature." By R. Ridgway. Washington, 1912.

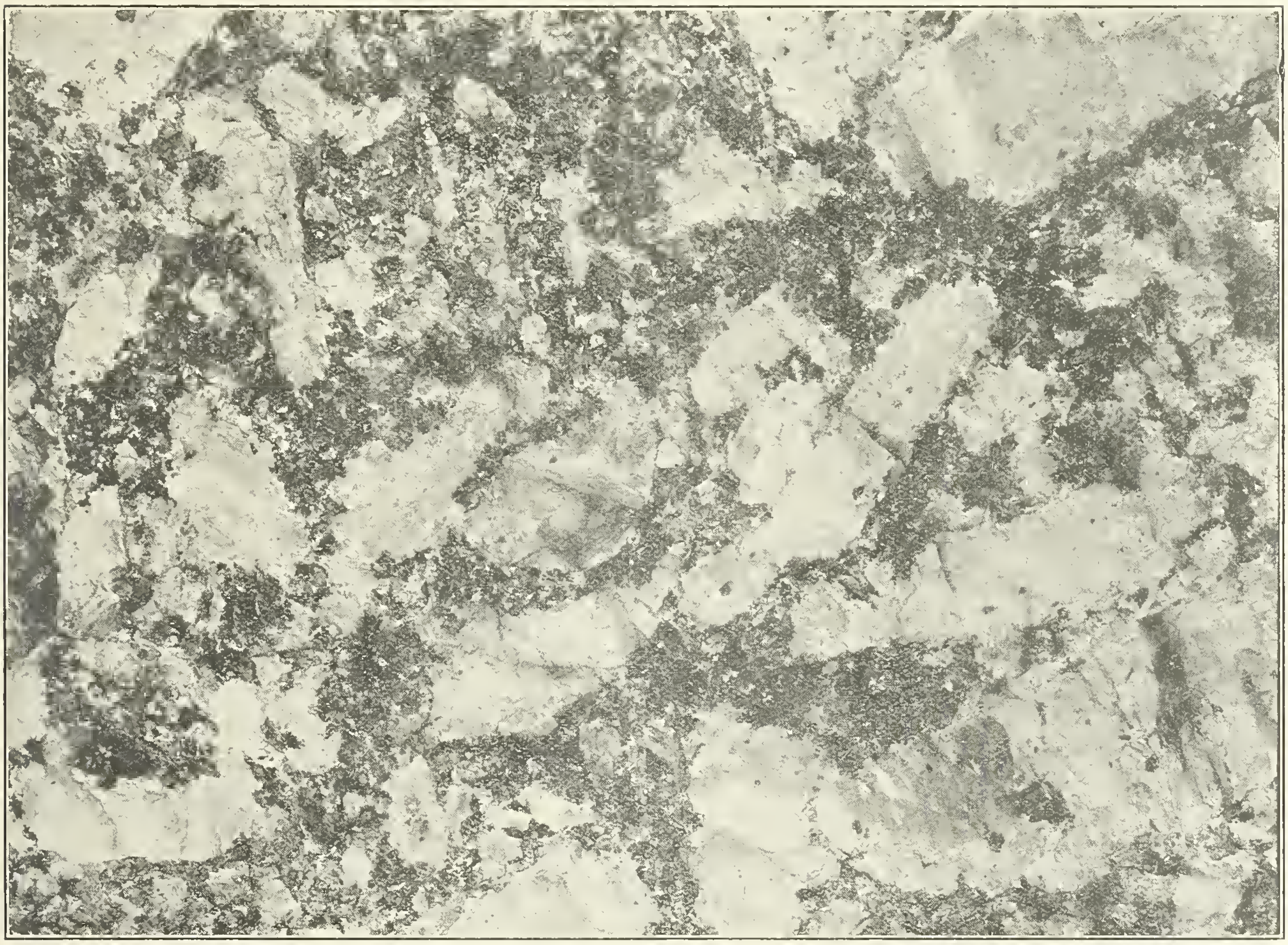

Fig. 2.—Portion of a block of porphyritic biotite-orthoclase-gneiss collected by C. E. Borchgrevink at Cape Adare on the "Southern Cross" Expedition. Quite similar to the rocks seen *in situ* by Priestley in the east wall of the Corner Glacier. Natural size. British Museum Photo. (Reg. No., B.M. 85752 (1)).

(d) The fourth exposure is at the north-western corner of the same *massif* of which Snowy Point and Cape Sastrugi form the southern promontories. Here the cliffs forming the east wall of the Corner Glacier show metamorphic rocks in place, but they could only be reached at one point owing to the great height and steepness of the screes which were lying at the extreme angle of rest and were exceedingly difficult to climb. However, evidence of the constitution of the cliffs was afforded in plenty by the abundant large masses of porphyritic gneiss many of which fell on to the screes during the time the party was encamped in the vicinity.

This porphyritic gneiss is a biotite-orthoclase-gneiss characterized by large phenocrysts of orthoclase (or microcline), frequently of a faint blue tint, in a groundmass of quartz, oligoclase, and biotite, with, as minor constituents, magnetite, apatite, zircon, and, in certain cases, tourmaline. The felspar of the phenocrysts is orthoclase in some cases and microcline in others. Oligoclase sometimes appears as small phenocrysts as well as in the groundmass.

In structure the rock varies from a porphyritic granite containing Carlsbad twins of felspar up to 5 cm. long (Fig. 2), through foliated eyed-gneiss, to a well-foliated fine-grained (0·25 mm.) gneiss or schistose gneiss. Those types in which the foliation is marked show cataclastic structures, bending of twin lamellae, and sometimes granulitic texture in all the minerals of the groundmass. Other types show in thin-section no signs of metamorphism except the development of myrmekite in the plagioclase. There is no doubt the rock represents a granite intrusion, which in parts has been strongly foliated. It is quite distinct from the hornblendic "augen-gneiss" of the Kukri Hills.

Farther to the south, the porphyritic gneiss is succeeded by a very fine-grained, black, well-foliated gneiss (1901), with abundant small flakes of biotite and small grains (0·1 mm.) of quartz. It is poor in felspar except where it is intruded by some thin stringers of aplite. This constitutes a very close approach to a true biotite-schist. It was seen *in situ* in the cliffs but only at a distance. Specimens were collected at the foot of the scree, the steepness of which rendered the actual exposure inaccessible.

The moraine at the south-eastern end of Corner Glacier afforded a remarkable abundance of metamorphic, plutonic, and hypabyssal rocks, but the variety of the former was not nearly so great as in the other moraines where unfortunately no opportunity of observing the rocks *in situ* presented itself. The prominent types met with, besides those already mentioned, were cordierite-gneiss and quartz-granulite.

(e) The fifth and last position in which the metamorphic rocks of this region were seen *in situ* was at the southern extremity of Inexpressible Island, in the front of which are the little bays to which the name of Evans Coves was given by the "Discovery" Expedition. The main mass of the island is formed by plutonic rocks, but to the south of this series the basal metamorphic rocks through which the plutonics have been intruded are to be seen *in situ*. It is the impression of the geologist of the present expedition that these rocks also dip farther to the west of north than the metamorphic rocks seen at the other exposures, but unfortunately the notes referring to them are lost and memory is treacherous after a lapse of nine years.

ERRATICS.

Metamorphic rocks formed between thirty and forty per cent. of the rocks examined in the various moraines, and the number and variety encountered suggest that the greater portion of the foothills and mountains to the north and west of the area is underlain by a metamorphic series.

The collection of erratics, including about 770 specimens, contains very few duplicates. Almost every specimen shows some character of interest, and has been collected and carried back for some particular reason. On this account thin-sections of nearly every specimen have been examined, and in 1914 and 1919 considerable time was devoted to the detailed petrography of them. As the rocks are known only as erratics it is not intended to publish the results of this detailed work except such as are necessary to give a clear idea of the nature of the rocks. It was found easy to separate the erratics into the main groups; biotite-gneiss, muscovite-biotite-schist, crystalline limestone, para-granulite, and graphitic mica-schist; but it is not considered advisable to attempt much further sub-division of these groups based on the examination of small pieces of boulders. After a brief description of the rocks of each of these main groups some remarks will be made on their probable distribution and relations.

Biotite-Gneisses.

A porphyritic biotite-gneiss and garnetiferous biotite-gneisses have been described already (pp. 148, 150). The remaining biotite-gneisses are all fine-grained dark rocks, sometimes granulitic and compact, sometimes very rich in biotite (dark-brown or almost black) and then highly foliated and approaching schists in texture. Some of them contain garnets; many of them contain cordierite, or sillimanite, or both. The felspar is usually orthoclase with slightly subordinate plagioclase: plagioclase, however, becomes dominant in some types, especially those carrying garnet. Hornblende is observed in only two cases, in each accompanied by indications of later injection of the biotite-gneiss by aplitic veinlets.

Five specimens from the Northern Foothills (1265, 1258, 1414, 1414A, 1419) include fine-grained garnetiferous biotite-gneiss with a rather abundant dull-Indian-purple biotite in small flakes (1414), and almost equally fine-grained (0·5 mm.) garnetiferous biotite-cordierite-gneiss with scarce sillimanite. All these have been injected by white veinlets of an acid rock and are violently folded to an extent not found elsewhere except in two erratics from Evans Coves. In addition there is a compact (0·6 mm. grain) garnetiferous biotite-cordierite-rock, showing typical "hornfels-texture" and consisting mainly of cordierite and biotite with quite subordinate oligoclase, and, as minor constituents, magnetite, green spinel, and garnet. The composition is very variable and in some parts garnet and biotite become very abundant and the garnets reach 3 mm. in diameter. The colour varies from deep-greyish-blue-green to dull-purplish-black. Two erratics of this type were found. The biotite in all these rocks is seal-brown with dull-Indian-purple tints shown by light reflected from the surface of the flakes: in thin-section its pleochroism is, β and γ burnt-sienna, α very pale primrose-yellow.

We have already dealt with the gneisses collected from the nunatak at the entrance of the Boomerang-Campbell Glacier, and at the same time mention was made of a boulder of the porphyritic biotite-gneiss collected from the inner moraine, south of the Boomerang Glacier. This moraine also yielded a specimen (1772), very like the garnetiferous biotite-cordierite-gneiss described above but containing more sillimanite. Another cordierite-gneiss (1774) from this moraine differs from the other gneisses found on the Boomerang-Campbell moraines: it is a compact (0·5 mm. grain) dark rock containing abundant quartz, brown biotite (γ and β burnt-sienna), and cordierite, with andesine felspar enclosing a few small garnets, and with a little sillimanite enclosed in the quartz. The cordierite is very unevenly distributed.

The remaining gneiss (1770), a dark, fine-grained (0·25 mm.), banded rock, is a sillimanite-bearing biotite-gneiss, free from cordierite, in which the sillimanite is concentrated in certain bands. The biotite in this rock gives in thin-section γ and β olivaceous-black, α pale primrose-yellow, and is black in the hand-specimen. The felspar, which consists of orthoclase with subordinate oligoclase, is fairly abundant.

The rest of the Boomerang-Campbell moraine yields a large number of gneisses which for convenience of description may be divided into three groups.

(1) Greyish, very fine-grained, banded gneisses (1278, 1500A, 1627, 1635, 1658) with a rather low but variable content of mica which is often concentrated in parallel bands. These rather resemble specimen 1770 (see above), but contain no cordierite or sillimanite. The biotite in all is almost black in hand-specimen and some shade of brown in thin-section: γ and β in (1627), vandyke-brown; in (1635), chestnut; in (1658), burnt-sienna. Most of these rocks contain garnet, either small (0·1 mm.) in 1658, or quite large (1·2 cm.) in 1627. The dominant felspar is plagioclase in the garnetiferous types. In 1627, containing the big garnets, it is labradorite, and orthoclase is absent. The groundmass is granulitic and the grain-size averages 0·25 mm.

(2) Three dark-green to black garnetiferous biotite-schists or gneisses (1657, 1659, 1637) are probably closely related to the above. The biotite (chestnut to pale-yellow) is very abundant forming 50 per cent. of the rock but is partly altered to chlorite. Garnets are abundant and some are 4 mm. in diameter. Andesine seems to be the only felspar present but there is much altered material which may be either felspar or cordierite. Rocks of this type have not been found elsewhere in the district.

(3) Gneisses of the third group are also fine-grained and very rich in biotite. They are well-foliated and the structure tends to be schistose. None of these contain garnets. One (1276) is practically free from felspar. 1639 and 1651, clearly closely allied, contain muscovite in addition to biotite. The remainder contain cordierite usually

with some sillimanite and in one case (1638) accompanied by andalusite. The pleochroism of the biotite is, γ and β burnt-sienna, α very pale yellow.

At Cape Sastrugi the erratics included two biotite-gneisses (1682, 1684), rich in biotite and plagioclase and resembling the group last described ; a black, finely banded gneiss, similar to 1901 from the east wall of the Corner Glacier ; and a thinly banded, grey muscovite-biotite-gneiss with granulitic texture (1667), which is intruded by dykes of tourmaline-pegmatite. A rock similar to this was found farther up in the eastern moraine of the Corner Glacier.

We mentioned above (pp. 148, 150) the gneisses of Cape Sastrugi and of the east wall of Corner Glacier, as probably in place there, and occurring also in the eastern moraine of the glacier. This moraine, in addition to the porphyritic biotite-gneiss and the black, banded, granulitic gneiss described above, yielded five specimens of the cordierite- and sillimanite-bearing gneisses.

Cordierite-gneisses free from sillimanite are represented by two compact, dark, garnet-bearing rocks. One (1744) contains garnets 1 cm. in diameter, and abundant cordierite. The rock is very much altered but may be related to the biotite-cordierite-rock (1414A) from the Northern Foothills. The other (1735), also garnetiferous, is very fine-grained (0·25 mm.), dull-purplish-black, and very rich in biotite. The felspar is microcline instead of the usual orthoclase ; garnet, tourmaline, and hypersthene all occur as accessories ; and the texture, as in the previous rock, is typical "hornfels-texture." * Here all the constituents are fresh.

Specimen (1754), dark-green almost black, is foliated and approaches a schist in texture. It contains cordierite in large plates enclosing biotite. Most of the biotite in this rock is altered to chlorite.

Rather more coarse-grained (1 mm. grain), distinctly banded, and with abundant biotite, is 1724 which contains both cordierite and sillimanite. The biotite, as in the three rocks just described, gives γ and β chestnut, α very pale yellow

The remaining specimen (1721) is an almost black schist, rich in biotite, with very abundant cordierite and sillimanite. All the constituents are remarkably fresh : in general characters and in the colour of the biotite the rock resembles 1770 (p. 152). (Pl. 2, Fig. 4).

The other moraines of the Corner Glacier contained two further examples of this last type (1490, 1491), but they are free from cordierite and sillimanite. They are dark, fine-grained, finely banded rocks, resembling 1770 in the hand-specimen and characterized by the same kind of biotite (γ and β olivaceous-black, α primrose-yellow), but magnetite appears as an accessory constituent. The remaining two specimens (1485, 1492) from these moraines rather resemble the grey, fine-grained, banded gneisses from

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* This is probably a contact metamorphosed sediment as it resembles the plagioclase-hypersthene-cordierite-hornfels described by V. M. Goldschmidt in the contact metamorphic rocks of the Christiania district. See Skrifter u.a. Videnskapsselskapet i Kristiania, 1911, Mat. Nat. Kl., Bd. 1, p. 160.

the Boomerang-Campbell moraine. One of them (1485) contains very small (0·6 mm.) garnets and also some muscovite in addition to the usual chestnut biotite.

Lastly, there are four specimens from the Priestley Glacier moraine. These include one representative of the grey, fine-grained, banded, garnetiferous gneisses (1313); one dark-brown, biotite-rich gneiss (1391) comparable to the cordierite-bearing gneisses described from the Boomerang-Campbell moraine; and two (1462, 1464) black and white, fine-grained, banded gneisses, with dark biotite (γ and β vandyke-brown), resembling 1627 (p. 152) from the Boomerang-Campbell moraine, but containing abundant cordierite and sillimanite.

Para-Granulites.

Among the erratics, mainly from the moraines of the Priestley and Corner Glaciers, are many specimens of rocks which are, clearly, metamorphosed, fine-grained, impure sandstones. They seem to be associated with rocks allied to the pyroxene-granulites (para-diopside-granulites) and it will be convenient to refer to the whole group as para-granulites. They can be classified roughly into four groups according as they contain mica, amphibole, epidote, or pyroxene as the predominant coloured mineral. The general characters of each class will be mentioned briefly.

Mica-Quartz-Granulites.

These are close-textured, even-grained (0·1-0·2 mm.), varying in colour from pale-grey of various shades to dusky-brown, and breaking readily into flat parallel-faced slabs. They consist mainly of quartz with small amounts of biotite, or biotite and muscovite, in very small flakes. Many of them contain small amounts of felspar. The accessory constituents are tourmaline, apatite, magnetite, and sphene, the last often abundant. Calcite becomes an important constituent in certain cases, and many types contain a pale-green amphibole as well as mica. All these rocks show evidence of foliation, the mica flakes being arranged in parallel layers, and the original clastic nature of the rock is still quite evident. They may be described under three heads:—

(1) Biotite-muscovite-quartz-granulites. Pale-grey to cinnamon-buff in colour, containing more muscovite than biotite. They contain patches of a turbid colourless mineral which is believed to be felspar.

(2) Biotite-quartz-granulites. Dusky-brown, showing small flakes of biotite on broken surfaces. Felspar is present as water-clear grains: it does not always show twinning but in one case oligoclase-andesine was definitely identified. A pale-green actinolitic hornblende and sphene are frequent as accessories. These rocks show very close association with the amphibole-quartz-granulites described below: bands of both kinds of rock frequently alternate in one specimen and are no doubt due to differences in composition in the original sediment (Pl. 2, Fig. 1).

(3) Calcite-bearing quartz-granulites. In 1703, a very pale olive-grey rock (Pl. 2, Fig. 3), small quantities of muscovite and biotite are present. Garnet as diablastic growths, colourless in thin-section and measuring up to 3 mm. in diameter, occurs in both cases. Calcite constitutes nearly fifty per cent. of the rock. In specimen 1782 a pale-green actinolitic hornblende is present, and there are probably transitions to the amphibole-quartz-granulites in which calcite appears as an accessory constituent.

Amphibole-Quartz-Granulites.

These closely resemble the biotite-quartz-granulites in texture. In colour they are court-grey or mineral-grey: the greenish grains of amphibole are clearly visible to the unaided eye giving the surface a mottled appearance and a quite characteristic lustre. They consist of quartz and felspar (andesine predominating) with quite abundant pale-green hornblende, and accessory biotite and sphene; less constant accessories are apatite, pyrites, and zircon (Pl. 2, Fig. 2).

The amphibole occurs both as crystals with well-developed prism faces and as irregular, much-embayed grains, showing "sieve-structure" and enclosing quartz and biotite. Its pleochroism is, α colourless, β light-grape-green, γ pale-glaucous-green; $\gamma : c = 20° - 22°$.

These rocks are not confined to the Priestley and Corner Glaciers. Erratics were found at Evans Coves Beach, Northern Foothills, Hell's Gate moraine, and at the nunatak at the entrance of the Boomerang Glacier.

Their original clastic nature can still be traced though less clearly than in the biotite-quartz-granulites. It is quite clear, however, in 1727 and 1608, both of which contain calcite and show resemblances to 1782 mentioned above. Small patches of crystalline limestone are adhering to one of the specimens (1275) which shows alternations of biotite- and amphibole-bearing bands.

Epidote-Quartz-Granulites.

These are represented by only six specimens (1257, 1264, 1441, 1723, 1732 1767). They are dark-ivy-green in colour with paler vetiver-green bands. The grain-size varies from 0·25 mm. to 1 mm., and they all possess a clearly banded structure. They consist mainly of quartz in more or less rounded grains, with epidote, pale-greenish chlorite, and small crystals of sphene. Patches of hornblende showing "sieve-structure" are sometimes present and seem to be in process of alteration. Garnet, warm-buff in colour, is occasionally enclosed by epidote. In the paler bands carbonates appear, closely associated with the epidote. The banding and the remains of clastic structure show that these rocks represent metamorphosed calcareous sandstones. They are probably closely associated with the other para-granulites.

Pyroxene-Granulites.

(Para-Diopside-Granulites.)

The rocks described under this heading are similar to some of the "acid-pyroxene-granulites" described by Walkom.* They are represented by 12 specimens from the Priestley Glacier and one from Evans Coves. In colour they vary from court-grey to slate-olive. The fracture is smooth, approaching conchoidal in some specimens. The mineral components are quartz, plagioclase, and diopside, with abundant sphene, some apatite, and usually calcite, as accessories. Compared with Nos. 960 and 1684 described by Walkom, duplicates of which are in the British Museum collections, they differ in containing more quartz and a more acid felspar (andesine.) The diopside shows the same characters as are given by Walkom. In addition to the diopside, some specimens contain a pale-green amphibole similar to that occurring in the amphibole-quartz-granulites. This amphibole may be distributed uniformly (1975), or may occur in bands replacing the diopside. Other specimens show biotite appearing in a similar way. Diopside, hornblende, and biotite all occur together in 1609, a specimen in some respects similar to Walkom's E96. There is evidently a close relation between these diopside-granulites and the biotite- and amphibole-bearing quartz-granulites just described. The grain of all these rocks is even and exceedingly fine (0·06–0·1 mm.), except that the diopside occasionally develops plates up to 0·6 mm. across. The texture may be described as granulitic. In many cases clear evidence of the original clastic structure can be seen.

A pea-green rock with bands (1 mm. thick) of paler ovoid patches and with very smooth fracture (1445) seems not to have attained such perfect recrystallization as the other specimens described. Patches of small grains of diopside and of quartz occur in a rather indeterminate groundmass of exceedingly fine grain and containing much carbonate and occasional patches of colourless zoisite.

All the specimens of these diopside-granulites show bands, of the same texture as the rest of the rock, but pale-buff in colour (vinaceous-buff to Tilleul-buff). In these bands grains of diopside, quartz, and felspar, quite similar to those seen in the green granulites, and about 0·04 mm. in diameter, are set in a groundmass which is partly indeterminate but which usually consists of diablastic growths of colourless zoisite and garnet. In one case (1323) garnet occurs alone as a diablastic growth enclosing the quartz, diopside, and felspar (labradorite.) Sphene in these buff-coloured bands is comparatively rare. The passage from the green granulite to the buff-coloured bands seems to be quite sharp, and no clear case could be made out for alteration in composition towards the middle of the band. A coloured band of the same kind occurs in a duplicate of Walkom's No. 960, in the British Museum collection [B.M. 1911. 135 (112)].

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* Walkom (A. B.). Brit. Ant. Exp., 1907–9. Geology. Vol. 2 (1916), pp. 161–168.

Closely allied to these buff bands is a drab-grey rock (1257) in contact with a diopside-granulite, which is rather more basic than any of those described above. This grey rock consists of colourless diopside, in hypidiomorphic crystals (0·3 mm. in diameter), and grains of quartz, set in a groundmass of garnet. The greater part of the garnet is colourless and shows anomalous double refraction, but it contains patches which are coloured warm-buff in thin-section, and are isotropic: these form clove-brown oval patches (2 × 5 mm.) in the hand-specimen.

Acid pyroxene-granulites of the kind described above are in places in contact with a quartz-diorite, the actual contact being seen in specimens (1373, 1256, 1375) from the Priestley Glacier moraine. The quartz-diorite will be described under the plutonic rocks: it shows signs of slight foliation. The contact effects are of the same character as those seen round the inclusions of pyroxene-granulite in the grey granite of Granite Harbour. Between the quartz-diorite and the granulite there is a band, $\frac{3}{4}$ inch in thickness, in which hornblende is the dominant ferro-magnesian constituent, and this is succeeded by several bands rich in hornblende which run through the granulite roughly parallel to the contact with the diorite. At first close together, these bands occur at wider intervals as they recede from the contact and finally disappear altogether. They are of the same character as the parallel bands of silicates developed around siliceous inclusions or intrusions in some metamorphosed limestones.

The amphibole has the characters of common hornblende: $\gamma : c = 15°$; pleochroism, α marguerite-yellow, β yellowish-olive, γ dark-greenish-olive: a narrow outer zone is frequently more green in colour. The crystals often enclose patches of biotite and seem to have formed at the expense of this mineral. As a rule they are subhedral, averaging 0·5 mm. × 1·5 mm., and show well-developed "sieve-structure." They enclose grains of quartz and felspar, and are set in a granulitic groundmass of quartz, orthoclase, and andesine, in decimillimetre grains. In another specimen (1256) the hornblendes are associated with colourless pyroxene showing equally well-developed "sieve-structure" and forming plates up to 1 cm. in diameter.

With one exception (1267), the pyroxene-granulites described above are from the Priestley Glacier, but other types are found on the eastern moraine of the Corner Glacier. One dark-green granulite showing very pale buff bands rich in calcite and pyroxene is closely allied to Walkom's basic pyroxene-granulites. Two others, very pale grey rocks, rich in colourless pyroxene, with orthoclase or microcline as the dominant felspar, resemble a diopside-microcline rock from the Southern Eyre Peninsula, South Australia, described by Tilley.* The colourless pyroxene in these rocks shows well-developed "sieve-structure" and forms plates 2 mm. in diameter enclosing felspar grains. The grain-size of the groundmass is about 0·15 mm.

We have pointed out in No. 5a (p. 139) the resemblance between some of the para-diopside-granulites and the "gneiss à pyroxène" of Brittany and elsewhere, and indicated that they probably represent altered calcareous or dolomitic sandstones. Here, as in the McMurdo Sound region, they are associated with biotite- and amphibole-quartz-granulites and with rocks rich in calcite if not actually with crystalline limestones. Very strong additional evidence of their derivation from calcareous sediments is afforded by the occurrence in them of the buff-coloured bands rich in garnet and zoisite, obviously representing bands of different composition in the original sediment, and recalling in composition and colour the pink bands in the calcflintas described in the metamorphic aureole of Cornwall by Flett and Barrow.*

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* Tilley (C. E.). Geol. Mag., 1920, vol. 57, p. 493.

Crystalline Limestones.

Some pale-buff bands occurring in one of the pyroxene-granulites (1762) were found to consist of calcite with quartz and colourless pyroxene. Another specimen (1759) shows a nodule, vinaceous-buff in colour, to which adhere fragments of pyroxene-granulite. It consists of calcite (0·3 mm. grain) with abundant grains (0·1 mm.) of colourless pyroxene and pale-buff uniaxial mica.

Similar in texture and from the same moraine is a diopside-bearing limestone (0·25 mm. grain) with some quartz, which in colour is white faintly tinged with green, and is in contact with a neutral-grey limestone (1757) similar in texture but containing abundant diopside, quartz, and graphite. The paler rock encloses a patch of grey quartz.

Scapolite and epidote appear in addition to diopside in a banded limestone from Snowy Point (1394). The general colour of the rock is tea-green with numerous white streaks, and in the centre of the specimen is a lens or "eye" of quartz 1-2 cm. thick. Hard bands, roughly parallel to the surface of this quartz lens, stand out on the weathered surface. The rock consists of calcite with abundant diopside, quartz, and scapolite, with a little hornblende. Epidote, colourless in thin-section, appears in some bands and is intimately associated with the pyroxene. Sphene is a constant accessory constituent. The hard bands consist almost wholly of silicates, the intervening softer bands being rich in calcite. The grain-size throughout averages 0·5 mm.

All these specimens must represent metamorphosed limestones or calcareous bands and nodules in the other sediments.

Erratics of white crystalline limestones are not found in the Terra Nova Bay region but, as we have pointed out elsewhere, these rocks are so friable under Antarctic conditions of weathering that they are not likely to travel as erratics far from their source. That true crystalline limestones are present in the district is indicated by the discovery of a fairly typical chondrodite-limestone (1751) as an erratic in the eastern moraine of the Corner Glacier. The hand-specimen is deep-neutral-grey with brown patches. It consists of calcite of about 0·5 mm. grain enclosing numerous crystals of chondrodite (0·25 mm. in diameter), very irregular in shape and surrounded by an almost colourless or faintly green chlorite. Minor constituents are graphite, enclosed in the chlorite, a trace of pyrites, and green spinel. The silcates form about 25 per cent. of the rock. The chondrodite is perfectly fresh: γ: cleavage = 30°: pleochroism, α cadmium-yellow, β and γ pale-cream. The chlorite is uniaxial and optically +, with α parallel to the base (001), and is therefore referred to penninite (Pl. I, Fig. 7).

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* Mem. Geol. Surv. England. The Geology of the Country around Padstow and Camelford, 1910, p. 71.

The Boomerang-Campbell moraine yielded no trace of metamorphosed limestones.

Muscovite-Biotite-Schists.

A number of specimens brought together under this heading, and all but two coming from the Priestley Glacier, though showing certain characters in common, may be separated into three groups.

(1) Pale to dark-neutral-grey rocks (1324, 1914, 1810, 1819, 1505), very fine-grained (0·1 mm.), moderately rich in biotite, and often with plates of muscovite visible in the hand-specimen. They are compact and, although parallel structure is well developed, are not very fissile. They consist of abundant quartz with biotite and muscovite, and occasionally a little felspar. The biotite is usually in small flakes but tends to aggregate in ovoid patches 1 mm. in diameter. Muscovite may form plates 2–4 mm. across. All contain small amounts of sillimanite, usually enclosed in the quartz but occurring in a rather exceptional manner in 1810. This rock consists of oval flakes of muscovite, up to 2 mm. in diameter, in a groundmass of quartz, with abundant small flakes of Dresden-brown biotite and a little muscovite, and some very irregular much-embayed grains of garnet. Rutile and a trace of apatite and zircon are also present. The muscovite flakes lie both parallel and perpendicular to the foliation. They sometimes enclose round grains of quartz, but most striking are the inclusions of radiating masses of fine fibres of sillimanite. These occur in almost every flake of muscovite and almost fill the flake. Oval patches of sillimanite, drawn out parallel to the foliation and enclosing some biotite, also occur. Masses of sillimanite needles clouding the centres of muscovite flakes, as in the specimen just described, occur in the metamorphosed Silurian grits and flags round the granite of New Galloway and have been described and figured by Miss M. T. Gardiner.*

This last described type may be a thermally-metamorphosed rock allied to the graphitic mica-schists described below, but others of these sillimanite-bearing muscovite-biotite-schists are probably related to the cordierite- and sillimanite-bearing gneisses already described. Cordierite was in fact found abundantly in a pale-drab-grey, fine-grained schist, free from muscovite but containing abundant, small, oval patches of biotite, and rather closely resembling some of the rocks referred to here.

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* Gardiner (Miss M. T.). Quart. Journ. Geol. Soc., 1890, vol. 46, p. 574. Pl. 23, Fig. 2; also Harker (A.). Petrology for Students. 1919, p. 268, Fig. 89 A.

(2) Two specimens from Priestley Glacier (1253, 1255), and one (1294) from Boomerang-Campbell moraine are pale-drab-grey rocks consisting mainly of quartz (0·1 mm. grain) with small flakes of biotite and muscovite. The micas are not very abundant, and the biotite again shows a tendency to gather into patches, sometimes with grains of pyrites at the centres. Tourmaline, apatite, and zircon are all present, but only in very small crystals sparingly distributed. One of these specimens (1294) contained a single crystal of andalusite.

(3) Finally there are two rather compact blackish-brown and dull-violet-black rocks, fine-grained (0·1 mm.), rich in biotite and muscovite, and with the groundmass plentifully strewn with graphite and brown tourmaline. One specimen (1484) contains unaltered crystals of andalusite, and aggregates of muscovite which may represent altered cordierite. The other (1386) contains oval "eyes" (1·5 × 4 mm.), pale-glaucous in colour and consisting wholly of colourless mica, which probably represent pseudomorphs after andalusite (Pl. 1, Fig. 6). One is struck by the resemblances between these two rocks containing andalusite pseudomorphs, graphite, and abundant tourmaline, and the graphitic schist of Heald Island which was found *in situ* in the neighbourhood of crystalline limestones.

Graphitic Mica-Schists.

Considerable interest attaches to a group of fine-grained black mica-schists characterized by an abundance of black graphitic dust, and by the development of pale-brown biotite in small ovoid patches giving the rocks a spotted appearance. These rocks are believed to represent slates or shales altered by thermal metamorphism near an igneous intrusion. They all come from the moraines of the Priestley Glacier, and almost entirely from the western moraine. They consist of flakes of pale biotite (γ and β burnt-sienna), quartz, abundant graphitic dust, and small grains of a black oxide of iron possibly ilmenite. Small flakes of muscovite occur in one specimen (1811). Short prisms of pale-brown and blue tourmaline are abundant in a coarser-grained and paler variety (1691). In the most compact forms the grain-size is 0·01 mm. or less, but there are bands in which the quartz grains average 0·06 mm., and others in which the biotite is better developed, flakes reaching 1 mm. in diameter. The foliation in these rocks is not very marked: there is a faintly parallel arrangement of the smallest biotite flakes and of the streaks of graphitic dust, but this is not shared by the larger biotite flakes, in fact it is noticeable that many of the biotite flakes have their cleavage faces inclined steeply but at varying angles to the planes of schistosity, thereby producing in certain sections a rough "herring-bone" pattern (Pl. 2, Fig. 5). Ovoid aggregates, averaging 1 mm. in diameter and made up of small flakes of biotite, occur in all these rocks. Almost invariably there is at the centre of the patch a crystal or lenticular patch of iron oxide sometimes surrounding or even entirely replaced by a yellow, highly refracting, and only faintly translucent mineral which is referred doubtfully to a form of leucoxene. In the finest-grained form (1448) the core consists of ilmenite, corroded and partly surrounded by colourless leucoxene, and often accompanied by crystalline calcite. In another case where the schist is unusually dark with graphitic dust (1786) these aggregates show a centre of iron-pyrites or pyrrhotite. The biotite of these aggregates does not differ from that in the groundmass. Graphitic dust and halo-forming inclusions are both excluded from the interior of these biotite aggregates but are concentrated at their outer edges.

There is some evidence to show that these graphitic mica-schists have been subjected to shearing stresses causing movement of the component minerals after the formation of the biotite aggregates, as some of the flakes of biotite in the aggregates have been torn at their exposed edges and streaked out in the direction of the schistosity (1923): in other cases light-coloured bands poor in graphitic dust have been squeezed out to form long lenticular patches in the darker rock (1784). This is particularly well seen in one specimen (1959) which shows evidence of considerable movement, and includes a band containing a few small garnets (0·25 mm.) and abundance of a mineral which is probably andalusite.

The relations of these graphitic mica-schists to other sediments is possibly indicated by a specimen (1822) which, in a thickness of about 2 cm., shows a schist of the kind described above, passing through a less graphitic type to a pale-greenish-grey quartz-schist, free from graphite and containing, in addition to biotite, a pale amphibole, calcite, and sphene.

There are three other examples, all from the Priestley Glacier, of dark mica-schists somewhat different from but closely allied to those just described. One of these (1789) contains numerous prisms of andalusite, 1·5 mm. thick and averaging 1 cm. in length, sometimes cruciform in cross-section (chiastolite) and showing the usual regular arrangement of included black dust. They are occasionally quite fresh at their centres, but in many cases are entirely altered to a confused mass of flakes of colourless muscovite. Closely allied to this is a "spotted schist" (1386) in which the abundant spots, now consisting in part of muscovite, probably represent andalusite or cordierite.

The remaining specimens (1704, 1813, 1818) are of a very striking rock, black, lustrous, fine-grained and schistose in texture, and characterized by numerous, long, thin lenticles of pyrrhotite, 1 to 2 mm. in diameter and sometines 1·5 cm. long. The groundmass consists of rather elongate grains of quartz (0·01–0·05 mm. in diameter), irregular flakes of pale biotite, and long thin flakes of colourless muscovite, the whole crowded with graphitic dust. Accessory minerals are tourmaline, and colourless ill-shaped garnets (0·02 mm.) very full of inclusions. The biotite shows pleochroic haloes surrounding a colourless mineral. The lenticles of pyrrhotite are roughly circular in cross-section. They occur frequently and are evenly distributed in bands in the rock. It is interesting to note that the pyrrhotite seems to form nuclei for "eyes" of quartz and biotite which frequently contain very pale yellow garnets in well-formed rhombic dodecahedra and showing symmetrical radial arrangements of inclusions. The garnets appear to start their growth from the pyrrhotite nuclei (Pl. 2. Fig. 6). Similar garnets were described by Miss. C. A. Raisin from the contact metamorphosed rocks of Bastogne, in the Belgian Ardennes.*

SUMMARY AND CONCLUSIONS.

Before summing up the general characters of the metamorphic rocks described above it will be useful to consider their distribution in the various moraines. This distribution is given in tabular form on p. 163, the numbers given being the number of specimens of each kind of rock collected at each locality. The outer (western) moraine of the Corner Glacier and the inner (eastern) moraine of the Priestley Glacier have been treated as one locality. At the foot of the table is shown the total number of metamorphic rocks and the total number of erratics of all kinds collected at each locality. In considering these figures one must bear in mind that it was naturally the object of the collector to bring back as great a variety of rocks as possible. The figures given in the table represent the variety of rocks at any one locality and not the relative abundance of the different kinds. For the true distribution and relative abundance of different types the field-notes taken at the time are more reliable than any deductions made from the numbers of specimens collected. and accordingly these notes are given in the tabular statement. It will be seen that, in a general way, they bear out the results deducible from the figures.

It is quite clear that the upper reaches of all four glaciers in this area cut through a basement series of metamorphic rocks which here, as in the McMurdo Sound region, underlies all other formations except the igneous rocks which have been intruded into them. The isolated exposure at Inexpressible Island must also belong to this series, and the numerous inclusions of gneisses and schists in the granite of the whole coastal belt bordering Terra Nova Bay suggest that, before the irruption of the granite, the whole or the greater part of this region was occupied by a similar formation.

The descriptions of the erratics show that there are in this area at least three, possibly four, groups of metamorphic rocks: the porphyritic biotite-gneiss, the other biotite-gneisses and granulites, and the graphitic mica-schists.

The porphyritic biotite-gneiss (p 150) is undoubtedly derived from a granite. and might well have been described with the other plutonic rocks. It has not suffered any very intense metamorphism but is foliated in parts, the foliation being more noticeable in specimens from the Priestley and Corner Glaciers than in those from

---

* Raisin (Miss C. A.). Quart. Journ. Geol. Soc., 1901, vol. 57, p. 64. Fig. 3.

TABLE SHOWING THE VARIETY OF METAMORPHIC ROCKS IN THE MORAINES.

Localities from which erratics were collected.	Evans Coves Beach.	Inexpressible Island.	Northern Foothills.	Hell's Gate moraine.	Nunatak at entrance of Boomerang Glacier.	Inner moraine S. of Boomerang Glacier.	Boomerang-Campbell moraine.	Snowy Point.	C. Sastrugi and moraine.	Eastern moraine, Corner Glacier.	Inner moraines, Priestley and Corner Glacier.	Moraine 1 (outer moraine), Priestley Glacier.	Vegetation Island.	
Porphyritic biotite-gneiss.				1	1	1	2			8	4	6		23
Garnetiferous biotite-gneiss.				1	5		1					2		9
Garnet- and cordierite-bearing biotite-gneiss.			4			3	16		4	14	4	2		47
Muscovite-biotite-schist.					1		1				1	7		10
Mica-quartz-granulite.	2	1	1							3	1	8		16
Amphibole-quartz-granulite.			1	1	1					3		3		9
Pyroxene-granulite (Para-diopside-granulite).	2		1									15		18
Diopside-microcline-rock.										2				2
Epidote-quartz-granulite.			1							6		2		9
Crystalline limestone.								1		4				5
Graphitic mica-schist.											5	12		17
Total metamorphics.	4	1	8	3	8	4	20	1	4	40	15	57		165
Total erratics collected.	147	18	57	22	23	16	53	3	28	64	46	273	21	771
Extract from field-notes on the erratics of several moraines made when the specimens were collected.				Gneiss; hornblende-granulite.		Quantities of biotite- and muscovite-schists and gneisses, many of them being garnetiferous.	Gneisses, both even-grained and porphyritic, mica- and hornblende-schist, quartz-granulite (?)			Porphyritic gneiss, even-grained gneiss, quartzite (? quartz-granulite), epidote-granulite. Mica-schist.		Pyritic and mica-schists of various types. Quartzite, quartz-schist.		

farther to the east. It is no doubt younger than the garnetiferous and cordierite-bearing gneisses and is probably intrusive into them; it may be also younger than the para-granulites and crystalline limestones. Its distribution is better known than that of the other rocks, for it is seen actually *in situ* at the nunatak at the entrance of the Boomerang Glacier and again in the eastern wall of the Corner Glacier. Evidence of its farther extension is given by its appearance as erratics in the moraines of the Boomerang-Campbell Glacier and in the western moraine of the Priestley, while farther afield large boulders have been found as far north as Cape Adare by C. E. Borchgrevink on the "Southern Cross" Expedition* (Fig. 2), and also by the Northern Party of this Expedition. Possibly yet another erratic of this rock is the block, several tons in weight, found by Mawson at Cape Irizar and described by him as carrying large rectangular anorthoclases†: this must have been in place at least 40 miles south of Evans Coves.

The other biotite-gneisses are, with the possible exception of some of the garnetiferous biotite-gneisses, of sedimentary origin. There is no clear indication of the mode of origin of the garnet-bearing biotite-gneisses of the nunatak at the entrance to the Boomerang Glacier or of the three garnetiferous biotite-schists from the Boomerang-Campbell moraine. All the other garnet-bearing gneisses are associated with the cordierite- and sillimanite-bearing gneisses or with the fine-grained grey and black banded gneisses, all of which were most probably derived from argillaceous sediments. This group appears to be represented in almost equal variety in the Boomerang-Campbell moraine and in the eastern moraine of the Corner Glacier, but the garnetiferous types were more abundant in the former locality and the garnet-free cordierite-gneisses in the latter. In the Priestley Glacier, western moraine, they are only represented by two specimens, their place being taken by the para-granulites.

The para-granulites, clearly, are metamorphosed impure sandstones, argillaceous, dolomitic, and calcareous. In some respects the degree of metamorphism which they have undergone seems to be less than that of the cordierite- and garnet-gneisses, and it may be suggested that the latter represent an older series of rocks than the para-granulites and the associated limestones. There is not sufficient evidence to justify more than a suggestion of this distinction, but the two groups of rocks do seem to be rather clearly separated both by petrographic characters and by their distribution. The mica-quartz-granulites and the amphibole-quartz-granulites appear both in the Corner Glacier and in the Priestley Glacier moraines. The para-diopside-granulites are restricted to the western moraine of the Priestley Glacier, and the diopside-microcline-rock and the limestones are found only in the eastern moraine of the Corner Glacier.

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* Prior (G. T.). Report on the Collections of Natural History made in the Antarctic Regions during the Voyage of the "Southern Cross." London, 1902, p. 322.

† Mawson (D.). Brit. Ant. Exp., 1907–9. Geology. Vol. 2 (1916), p. 230.

The whole group is entirely absent from the moraines of the Boomerang-Campbell Glacier where the garnet- and cordierite-gneisses are so prominent.

The muscovite-biotite-schists are mainly confined to the Priestley Glacier but they do not constitute a very satisfactory group, for while two of them resemble the andalusite-schist of Heald Island, which we know to be associated with the crystalline limestones in that area, others show affinities with the cordierite- and sillimanite-bearing gneisses, and one at least has characters which may be due to thermal metamorphism and so may be related to the graphitic mica-schists.

As to the age of this metamorphic series, the evidence of the Pre-Cambrian age of the metamorphic rocks of the McMurdo Sound region applies equally to the rocks of this area, for there is every reason to suppose that the metamorphic rocks in both areas belong to the same series.

The graphitic mica-schists are quite distinct from the rest of the metamorphic rocks of this region, and perhaps should have been described only in the part dealing with the sedimentary rocks. Boulders of them were found in considerable quantities in the western moraine of the Priestley Glacier where they are not associated at all with the other types of metamorphic rocks, but occur in conjunction with a very few plutonic and dyke rocks. Interesting and perhaps significant features of their occurrence are the presence in the moraine of a distinctly carbonaceous facies of the Beacon Sandstone, and also of volcanic rocks undoubtedly of much older appearance than those yet found elsewhere along the coast of South Victoria Land. The metamorphism shown by these rocks is such as can be attributed to thermal metamorphism in the neighbourhood of an igneous intrusion, and is of a very much less intense type than any shown by the rocks of the main metamorphic series. There is no evidence as to the nature of the igneous intrusion which produced the metamorphism of these graphitic schists. The only intrusion known in the immediate vicinity is the porphyritic biotite-gneiss seen in the east wall of the Corner Glacier, but this is in parts very much foliated and is probably earlier than the graphitic schists. In age they must be later than the Pre-Cambrian metamorphic series and probably older than the Beacon Sandstone; *i.e.* pre-Lower-Devonian. Their exact age, however, and their relation to the series of sedimentary and volcanic rocks with which they are associated cannot be determined until this very interesting region has been revisited by a party with a more unrestricted commission and with more time at its disposal.

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LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
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PLATE 1.

No. 5a.—Rocks from McMurdo Sound region.

Fig. 1.—Cordierite-bearing garnet-gneiss. *In situ* in hill at the snout of Suess Glacier, Dry Valley. No. D9F. Magnification 30 diameters. (p. 141).

Fig. 2.—Andalusite-bearing graphitic muscovite-schist. *In situ* at the top of Heald Island, Koettlitz Glacier. The figure shows an end of one of the long pseudomorphs. The black grains are graphite. The small colourless prisms are tourmaline. No. D2K. Magnification 30 diameters. (p. 140).

Fig. 3.—Chondrodite-limestone with abundant spinel. *In situ* opposite Suess Glacier, Dry Valley. No. D12F. Magnification 17 diameters. (p. 135).

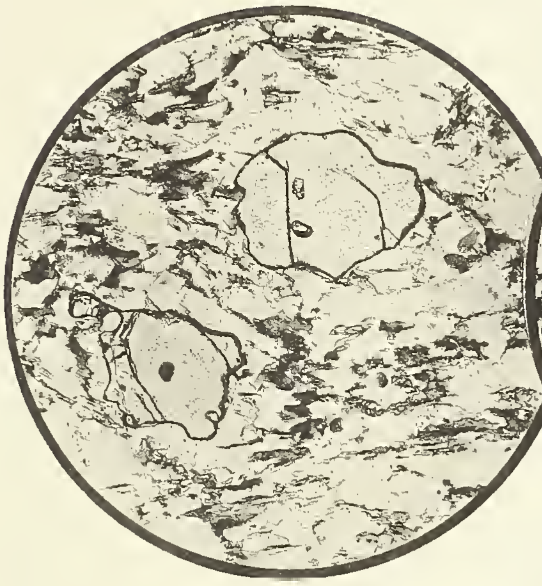
Fig. 4.—Garnet-sillimanite-gneiss. *In situ* opposite Suess Glacier, Dry Valley. No. D14F. Magnification 14 diameters. (p. 141).

No. 5b.—Rocks from the Terra Nova Bay region.

Fig. 5.—Garnetiferous biotite-gneiss. From the Boomerang Glacier. No. 1497. Magnification 30 diameters. (p. 148).

Fig. 6.—Muscovite-biotite-schist, with pseudomorphs probably after andalusite. From Priestley Glacier. No. 1386. Magnification 26 diameters. (p. 160).

Fig. 7.—Chondrodite-limestone, with chlorite, graphite, and dark-green spinel. From the eastern moraine of Corner Glacier. No. 1751. Magnification 30 diameters. (p. 159).



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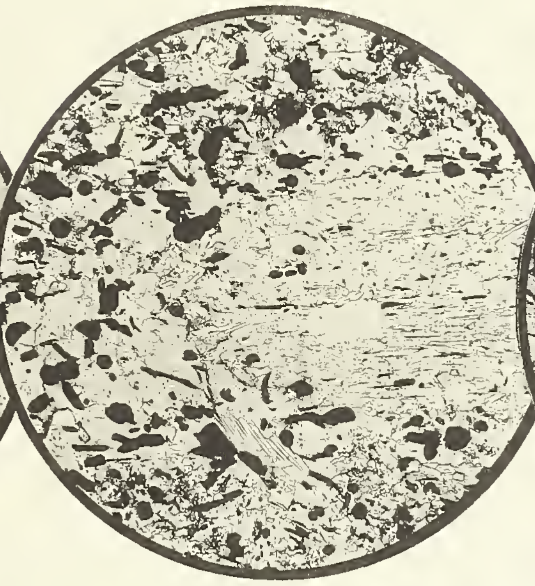

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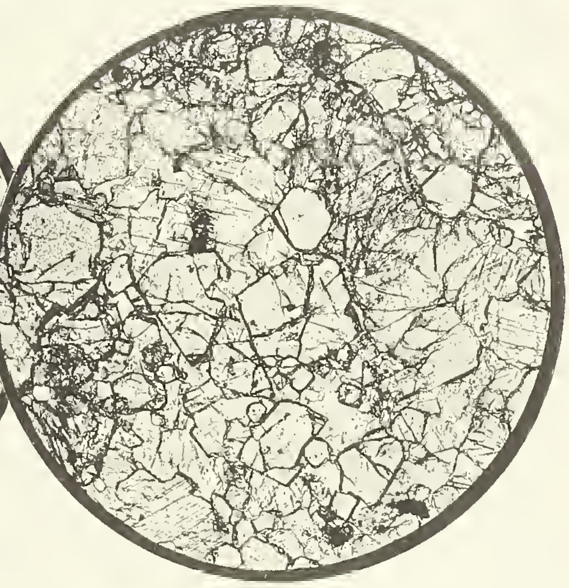

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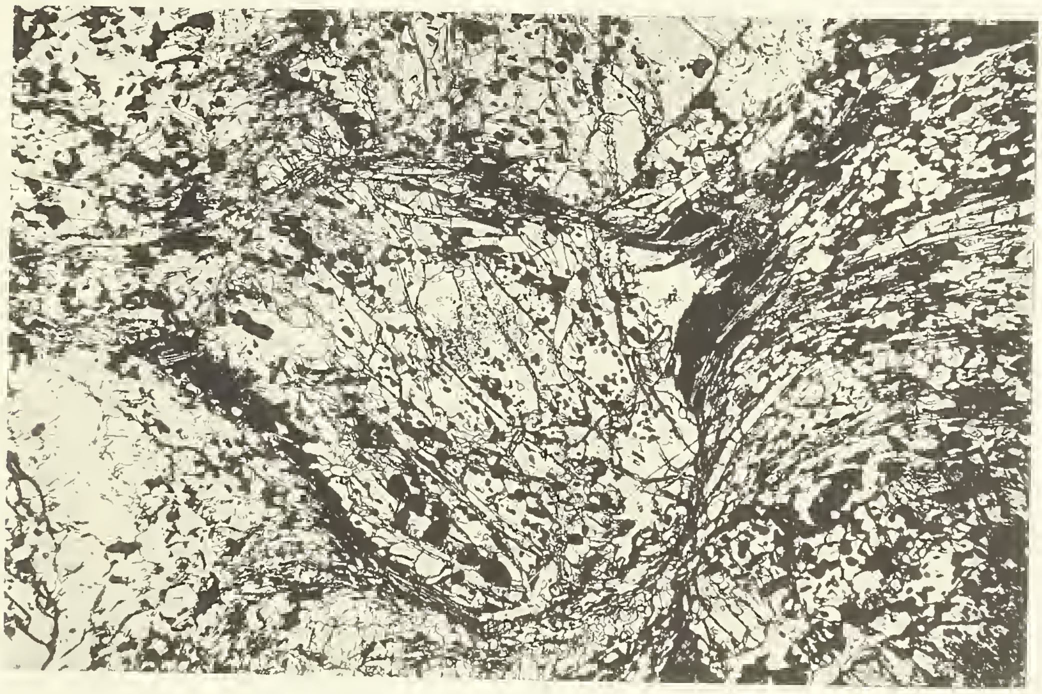

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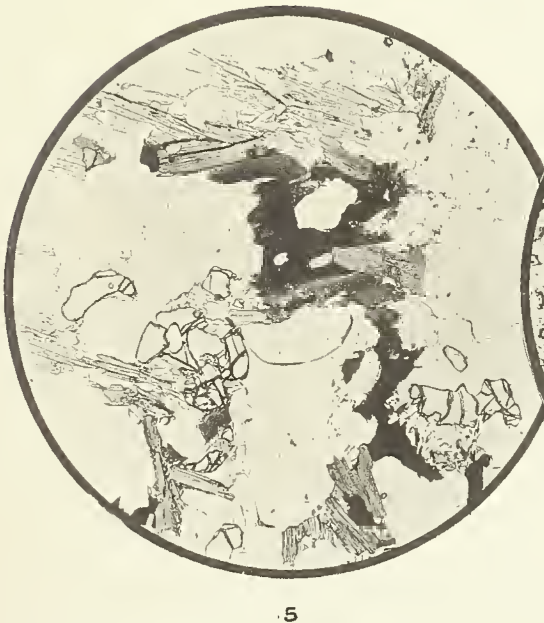

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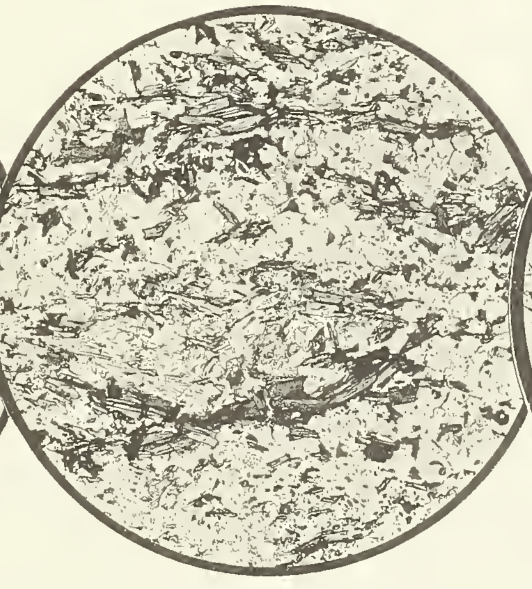

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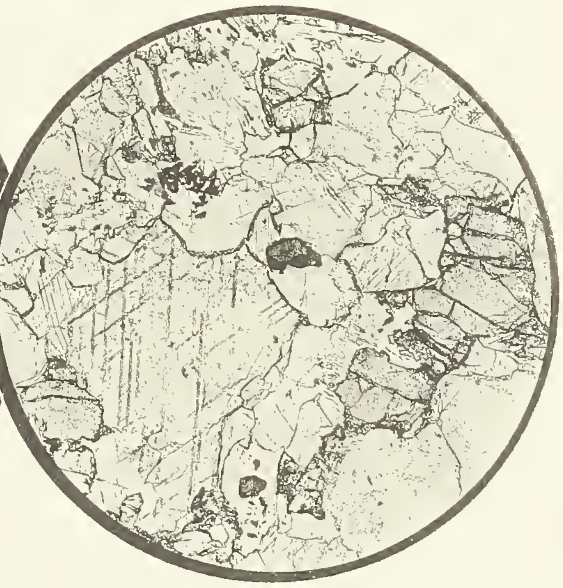

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Metamorphic Rocks

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PLATE 2.

No. 5b.—Erratics from the Terra Nova Bay region. The magnification in each case is about × 30 diameters.

Fig. 1.—Biotite-quartz-granulite. From Evans Coves. No. 1528. A crystal of pale-green amphibole near the top left-hand, and of sphene near the top right-hand edge. (p. 154).

Fig. 2.—Amphibole-quartz-granulite. From eastern moraine, Corner Glacier. No. 1727. (p. 155).

Fig. 3.—Calcite-bearing quartz-granulite. From Priestley Glacier. No. 1703. Showing a patch of colourless garnet. (p. 155).

Fig. 4.—Cordierite- and sillimanite-bearing biotite-gneiss. From eastern moraine, Corner Glacier. No. 1721. Highly foliated. The colourless cordierite in the centre of the field shows some faint pleochroic haloes surrounding small inclusions. Taken in polarised light. (p. 153).

Fig. 5.—Graphitic mica-schist. From Priestley Glacier moraine. No. 1622. (p. 160).

Fig. 6.—Graphitic mica-schist, with colourless garnet growing out from a nucleus of pyrrhotite. From Priestley Glacier moraine. No. 1813. (p. 162).

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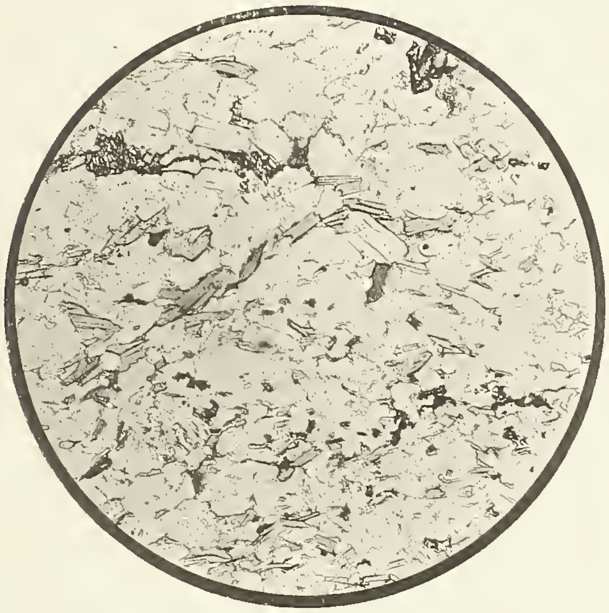
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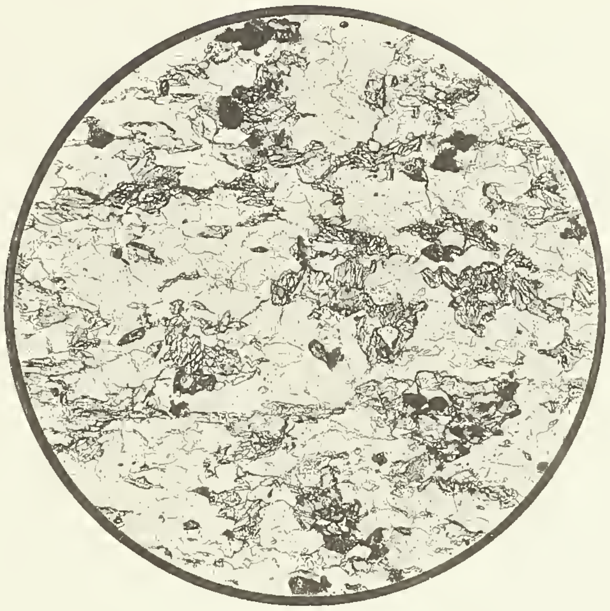
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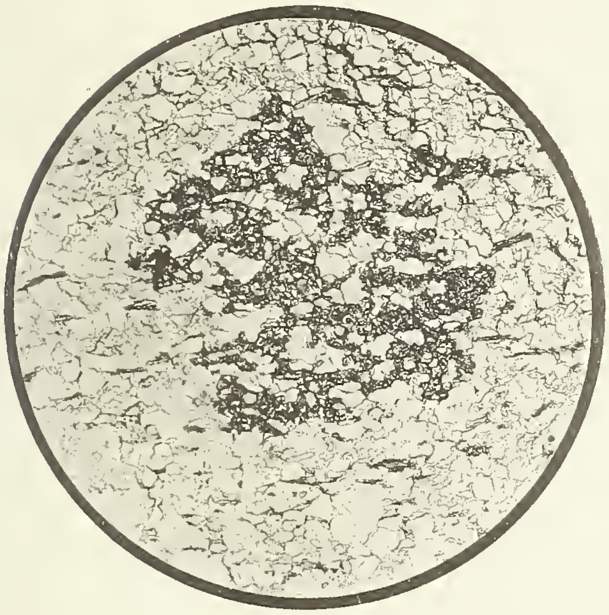
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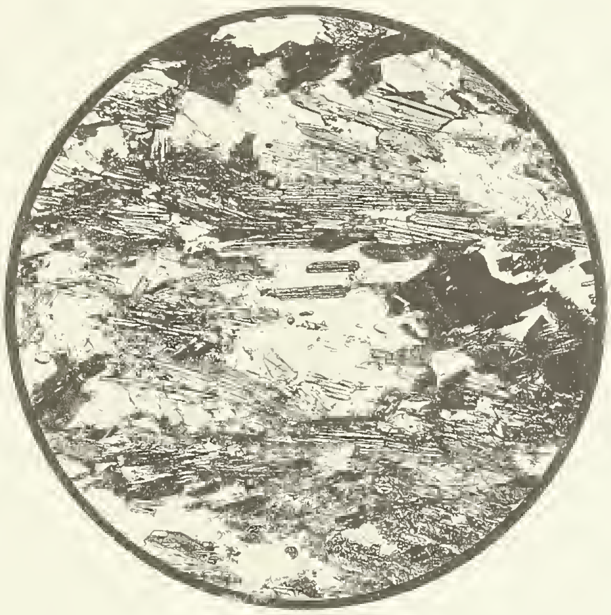
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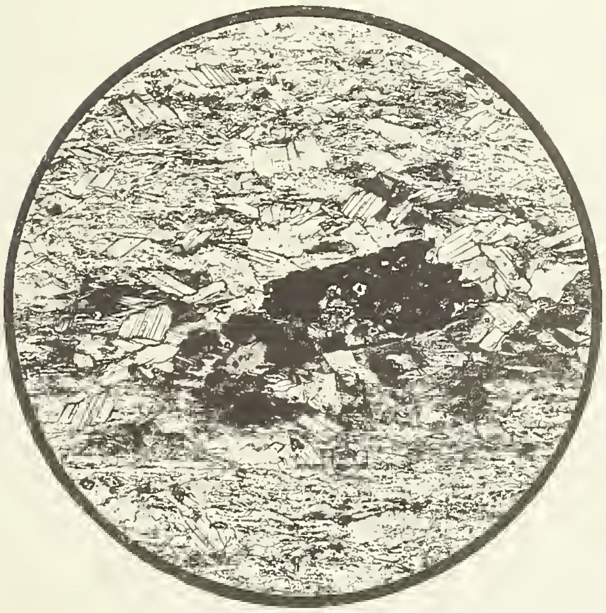
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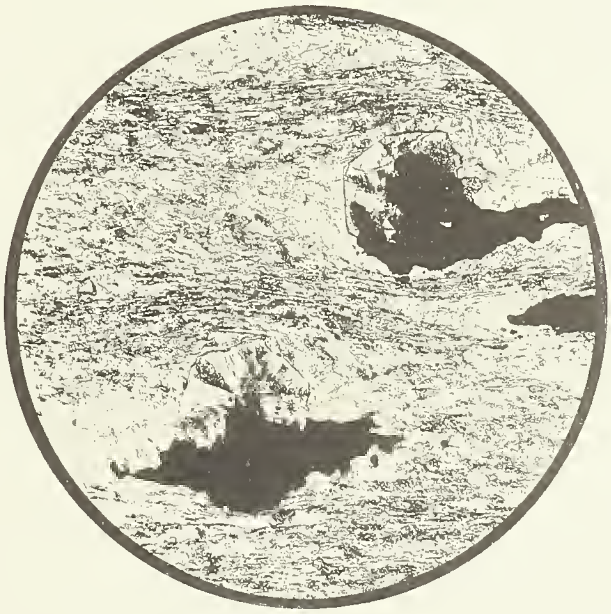
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Metamorphic Rocks.

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BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910.

NATURAL HISTORY REPORT.

GEOLOGY. VOL. I. No. 6. Pp. 167–227.

THE PLUTONIC AND HYPABYSSAL ROCKS OF SOUTH VICTORIA LAND.

BY

W. CAMPBELL SMITH, M.C., M.A., F.G.S.,
Fellow of Corpus Christi College, Cambridge; Assistant in the Mineral Department of the British Museum.

WITH FOURTEEN FIGURES IN THE TEXT, ONE PLATE, AND TWO MAPS.

B. M.
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LONDON:
PRINTED BY ORDER OF THE TRUSTEES OF THE BRITISH MUSEUM.
Sold by Longmans, Green & Co., 39 Paternoster Row, E.C. 4; B. Quaritch, Ltd., 11 Grafton Street, New Bond Street, W. 1; Dulau & Co., Ltd., 34–36 Margaret Street, Cavendish Square, W. 1; Oxford University Press, Amen Corner, E.C. 4; Wheldon & Wesley, Ltd., 2, 3, & 4 Arthur Street, New Oxford Street, W.C. 2;
Oliver & Boyd, Tweeddale Court, Edinburgh;
and at the
British Museum (Natural History), Cromwell Road, London, S.W. 7.
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[*Issued 26th January, 1924.*]

THE
PLUTONIC AND HYPABYSSAL ROCKS OF SOUTH VICTORIA LAND.

BY

W. CAMPBELL SMITH, M.C., M.A., F.G.S.
Fellow of Corpus Christi College, Cambridge.
Assistant in the Mineral Department of the British Museum.

WITH FOURTEEN FIGURES IN THE TEXT, ONE PLATE, AND TWO MAPS.

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THE McMURDO SOUND REGION.*

PLUTONIC ROCKS AND ASSOCIATED APLITES AND PEGMATITES.

Previous reports on the plutonic rocks of South Victoria Land have established the fact that the granites of the McMurdo Sound region belong in the main to two types, a grey biotite-granite (Pl. 1, Fig. 3) and a pink hornblendic biotite-granite probably somewhat younger in age. The grey biotite-granite is later than the metamorphic series and earlier than the Beacon Sandstone which in places rests directly upon it. It contains very many included masses of the metamorphic rocks and shows signs of foliation, particularly along the coast of McMurdo Sound, which is presumably near the margin of the mass. The pink hornblendic granite shows no sign of foliation, contains no included masses of metamorphic rocks, and is believed to be newer than the grey biotite-granite.

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* Based on the field-work and collections of Mr. F. Debenham, geologist on the Expedition.

Grey Biotite-granite [Granite Harbour type]

(*Hornblende-free Granodiorite*).

The prevailing type has been described by Dr. G. T. Prior* as "somewhat gneissic in character, and shows signs of parallel structure in the arrangement of the shreds of biotite. It consists of large plates of orthoclase and oligoclase, with interstitial quartz-mosaic (cataclastic structure) and flakes of biotite. The oligoclase is mostly idiomorphic, and shows both albite- and pericline-twinning. A little sphene and small rounded zircons are present as accessory minerals. The rock shows evidence of pressure in the strain-shadows in the quartz, as well as in slight bending of the twin lamellae and fracture of the crystals of oligoclase." The sphene recorded by Prior is present as large crystals in his original section, but it has not been seen in any other sections and seems to be an unusual constituent. Orthite and apatite are present in every case. The appearance of the rock in the field is illustrated in Pl. 1, Fig. 3.

A typical specimen of the grey granite (D9G) from Cape Geology was analysed by Mr. E. D. Mountain of the Mineral Department, British Museum, with the results given in Table I, column 1.

The calculated norm is :—

Q	27·48	hy	5·70
or	21·13	mt	0·46
ab	32·49	il	0·61
an	16·12	ap	0·34
C	0·61		

The C. I. W. P. co-ordinates are I. 4. 3 (2). 3. Sub-rang Amiatose.

For comparison, analyses are quoted of a biotite-granite from Royal Batholith, Phillipsburg Quadrangle, Montana,† and of a protogine from Cevins, Haute Savoie.‡ The Royal Batholith granite has been classified as quartz-monzonite by W. H. Emmons and F. C. Calkins.

The mode of the grey granite has not been calculated. The biotite which is present§ would require much of the potash from the normative orthoclase, so that in the rock itself plagioclase must predominate to a very marked degree.

The mineral composition of the rock may be expressed by naming it a *hornblende-free granodiorite*.

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* Prior (G. T.), Nat. Ant. Exp., 1901-4, Natural History, vol. 1 (1907), p. 125.

† Emmons (W. H.) and Calkins (F. C.), U.S. Geol. Surv., Prof. Paper 78, 1913, p. 109.

‡ Osann (A.), Beitr. z. chemische Petrographie, Teil 2, 1905, p. 12; and Ritter (E.), Les Massifs de Beaufort et du Grand-Mont, Thèse fac. d. Sci. de l'Univ. Genève, 1894, p. 27.

§ Estimated from measurements on three thin sections as between 11 and 15 per cent. See p. 227.

TABLE I.

	1.	2.	3.
SiO_2	68·33	68·40	68·60
Al_2O_3	16·56	16·34	16·15
Fe_2O_3	0·34	0·17	—
FeO	2·82	1·56	2·93
MgO	0·61	0·64	0·66
CaO	3·43	3·97*	2·35
Na_2O	3·85	3·39	5·54
K_2O	3·56	3·91	3·31
H_2O+	0·38	0·55	—
H_2O-	0·04	0·29	1·04 (ig.)
TiO_2	0·29	0·29	—
P_2O_5	0·23	0·22	—
MnO	tr.	0·07	—
	100·44	99·80	100·58

1. D9G Grey granite, Ridge Rocks, Cape Geology, Granite Harbour.
2. Quartz-monzonite, Royal Batholith, Phillipsburg Quadrangle, Montana.
3. Protogine, granitic type, Cevins, Haute Savoie.

Some information on the distribution of the grey granite is to be found in the account of the Glaciology of South Victoria Land by Sir T. W. Edgeworth David † and R. E. Priestley in the reports on the National Antartic Expedition of 1907–9.

These authors observed a grey granite forming Mounts Larsen, Gerlache, and Crummer (Fig. 1). A gneissic grey granite forms a small promontory SW. of Prior Island at the mouth of the Davis Glacier, and appears again at Depot Island, Dunlop Island, and Cape Ross, where it was seen to contain many inclusions of "quartzite." In Granite Harbour it is believed to form Mount Marston and Mount England, and there are three or four outcrops at Marble Point. It is not possible to be certain that all these outcrops belong to the same kind of granite or to the same intrusion at all points along the two hundred miles of coast between Mount Larsen and New

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* CaO includes BaO 0·15, SrO 0·05.

† David (T. W. E.) and Priestley (R. E.), Brit. Ant. Exp., 1907–9, Geology, vol. 1 (1914). pp. 64–85.

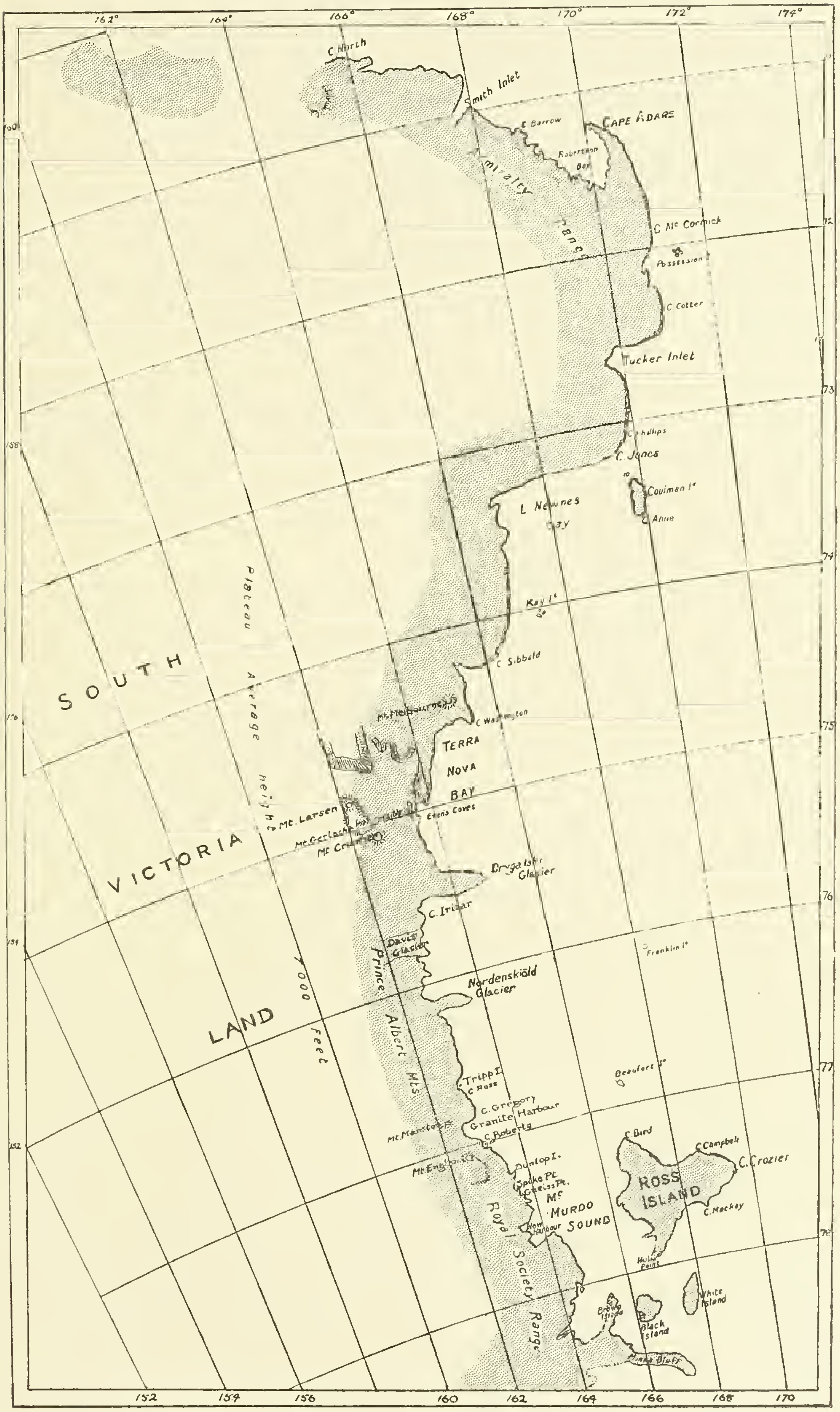

FIG. 1.—Map of Coast of South Victoria Land. Scale, approximately 1 : 4,100,000 along meridians.

Harbour, but we shall show later that there is no marked difference revealed by the analyses of the granites of Mount Larsen and that of Granite Harbour, and evidence is in favour of all the occurrences being exposures of one enormous laccolite of which the margin is exposed along the coast.

The granite seen on the coast exposures is in nearly every case much more strongly foliated than the rock of Granite Harbour, but specimens, apparently not far from their outcrops, quite similar to the Granite Harbour type were found by Priestley on his journey down the coast in 1912 at Tripp Island, Gregory Island, Cape Ross, Cape Roberts, Dunlop Island, Gneiss Point, and Marble Point, so that the distribution of these erratics is evidently very uniform along this part of the coast.

A gneissic granite is recorded by Debenham as intrusive in the metamorphic series at Cape Bernacchi, and it is found *in situ* at Spike Point, Gneiss Point, and also near Granite Harbour at Point View (2 miles west of Cape Roberts), and at Cape Roberts itself, where there are numerous aplite veins running in all directions and great abundance of included masses of metamorphic rocks which seem to preserve the general north and south strike.

In Granite Harbour itself the grey biotite-granite was found *in situ* at the base of the Piedmont Tongue (4 miles west of Cape Roberts), at Cape Geology, and forming the whole of The Flatiron below the 1,000-foot contour, and the lower part of Cuff Cape: farther west it appears near the top of Mount Suess and at the northern end of Gondola Ridge (D81G) (Fig. 2). Wherever seen it contains inclusions of metamorphic rocks. At the typical exposure at Cape Geology (D9G) the granite is porphyritic, the phenocrysts of orthoclase often reaching 3 inches in length. These phenocrysts are frequently reddish in colour and, in fact, there is a tendency for the weathered rock to assume a reddish tinge. The master-joints run roughly NE. and SW., parallel to the direction of the prominent dikes in this area.

In the Ferrar Glacier region very little material was collected from the exposures of the grey granite except from a hill by Double Curtain Glacier at the SE. end of the Kukri Hills, which is farther east than any of the granite exposures hitherto recorded. H. T. Ferrar's report on this region dealt with many exposures of the granite, but, owing to some confusion between the two types of granite, their distribution cannot be made out very clearly. The specimens collected by the Discovery Expedition of 1901–4 have, however, been re-examined, and it is found that the typical grey biotite-granite is represented by: No. 562 from the granite hillock N_2* at about 3,500 feet [i.e. 1 mile west of G_4]†; No. 563, collected by Dr. R. Koettlitz at e_6 [the eastern Granite Knoll] at 3,000 feet, full of inclusions and

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* References are to the geological map published with Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907).

† References in square brackets are to the map of the Ferrar-Koettlitz District, No. I, issued with this Number.

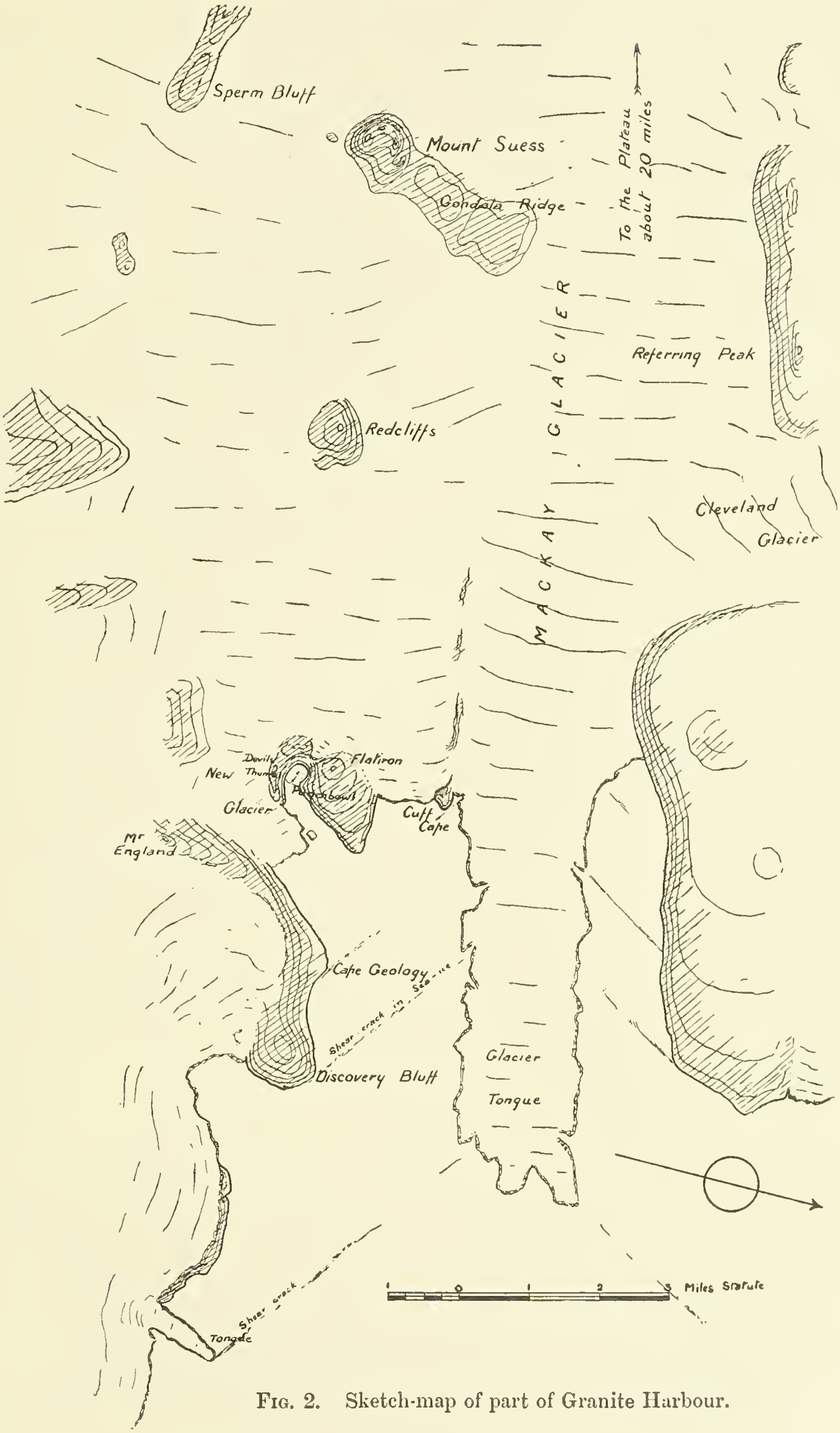

Fig. 2. Sketch-map of part of Granite Harbour.

probably belonging to the hornblendic facies described below; No. 708 at the level of the ice below D_2 in the Kukri Hills; and Nos. 706 and 707 from 500 feet higher at the same place. The last two are slightly coarser in grain than the typical granite: they show a contact with the dolerite which has a chilled edge at the contact. Rather less certainly identified as belonging to the grey biotite-granite is a specimen (626) collected by Lieut. R. W. Skelton at E_4 [Snow ridge south of Descent Pass] at a height of 5,000 feet; while Ferrar believed the grey biotite-granite formed the greater part of Sentinel Peak and hill *m* [6,000 feet] in the Kukri Hills.

Apart from the last two unconfirmed observations there is a remarkable uniformity about the levels of the upper surface of the granite where it is capped by the lower dolerite sill in the Ferrar Glacier region. Thus the top of the grey granite below D_2 is 500 feet above the ice, i. e. about 3,500 feet above sea-level; the top of the lower granite in the eastern end of the Cathedral Rocks is about 3,000 feet; on the north side of the Kukri Hills about the same; and the top of the lower yellow band in Solitary Rocks, which Priestley has identified as granite,* is 3,000 feet.

Debenham believes the horizontality and general level of the upper surface are maintained in Granite Harbour, but at The Flatiron the pink granite is seen as low as 1,000 feet, while at the Punchbowl it runs down to the 300-foot contour (Fig. 3).

In the Ferrar Glacier region the granite is always separated from higher rocks by a sill of dolerite, but this seems generally to have been intruded at the upper surface of the granite,† and the abundance of inclusions of metamorphic rocks possibly indicates that we are dealing with portions near the top of the original laccolite.

It is doubtful if the base of any part of the granite intrusion has ever been seen. Ferrar found metamorphic rocks at the base of Cathedral Rocks, but they may only form part of a large included block. Again, he records "augen-gneiss" in place at the base of D_4 with only 3,000 feet of granite above it, but this is evidently near the margin of this part of the intrusion, for the metamorphic rocks come on in strength a little to the east, and the granite is only recorded farther east near the base of Double Curtain Glacier, where it possibly forms a small intrusion in the metamorphics.

Xenoliths and hornblendic patches in the grey granite.

It has been mentioned already that the grey granite contains numerous inclusions of the metamorphic rocks, gneisses, granulites, and limestones, which represent foundered portions of the roof of the granite laccolite. The gneisses seem to have suffered no absorption: the sharpness and angularity of their outlines are well shown

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* Priestley (R. E.), The Heart of the Antarctic, 1909, vol. 2, Appendix 3, p. 320.

† See Figs. 1, 2, 6, and 7 in No. 4 of this report; also Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907), p. 37, Fig. 18.

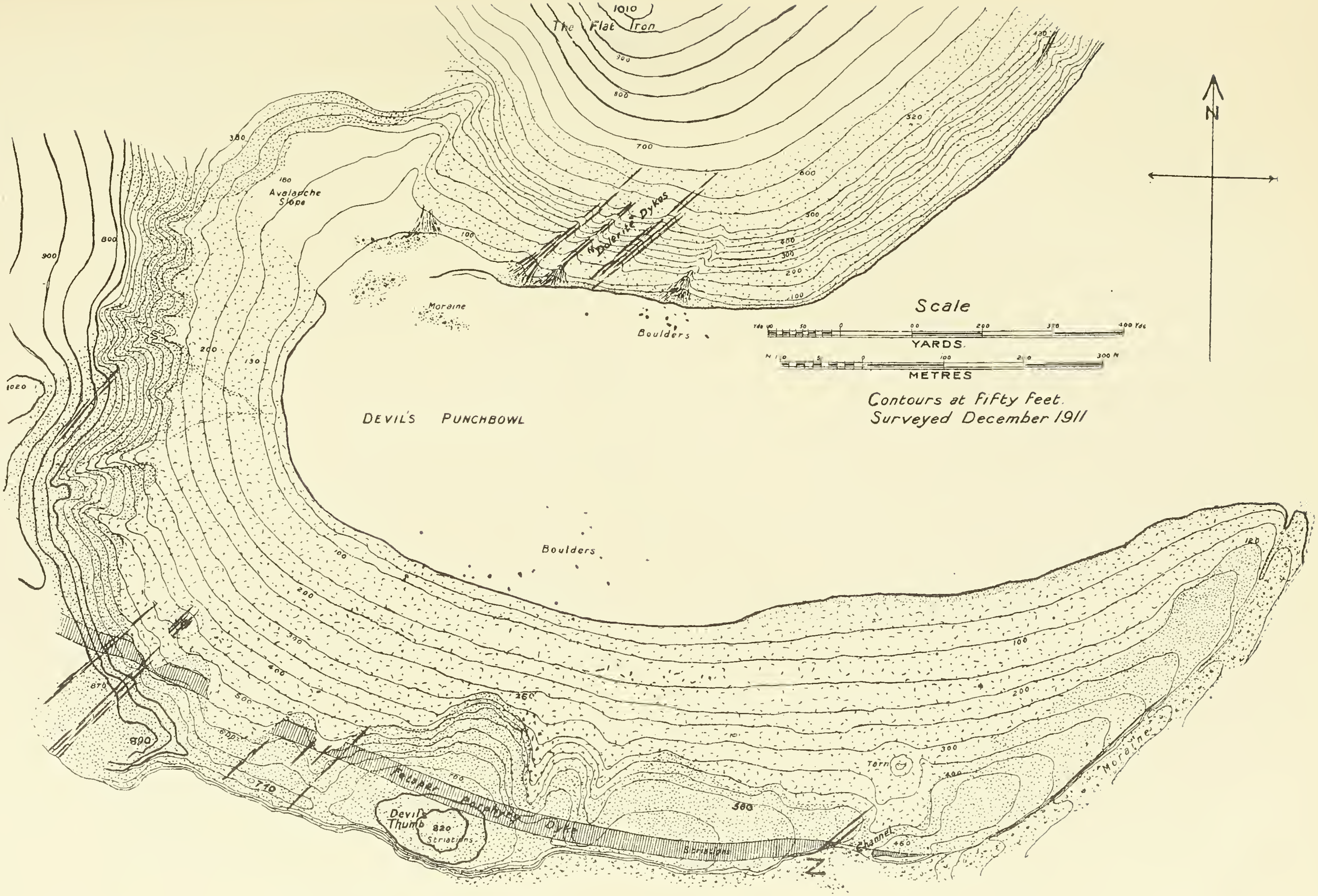

FIG. 3.—Devil's Punchbowl, Granite Harbour. From the plane-table survey by Mr. F. Debenham.

in the photograph of gneiss included in granite at Cape Geology (Pl. 1, Fig. 1). The pyroxene-granulite inclusions, on the other hand, have reacted strongly with the invading granite and, except in the case of large inclusions, remain only as cores of spheroids in an orbicular granite shortly to be described. Limestone, although the most widespread of the metamorphic rocks in the Ferrar Glacier region, is represented only by two very large inclusions, Marble Dike (Pl. 1, Fig. 6) and Marble Outcrop, and it is believed that all the smaller ones have been completely absorbed.

Specimens of the orbicular granite mentioned above were collected at Boulder Beach near Cape Geology (Pl. 1, Fig. 2), and at point K on The Flatiron (Fig. 4). The granite in which the orbicular structure has developed is the grey granite described above, and the orbicular structure itself is clearly traceable to reaction with inclusions of the para-pyroxene-granulites, although in many of the spheroids the nucleus has been entirely replaced. Hornblende plays a very important part in these orbicular structures. The spheroids themselves have a well-marked concentric structure combined with a less definite radial arrangement of the hornblende and, in some cases, of biotite.

The edges of the included pyroxene-granulite are quite sharp, pyroxene disappears entirely, and the first band in the orbicular structure consists mainly of hornblende crystals, with well-marked sieve-structure due to numerous inclusions of rounded grains of felspar and quartz. Proceeding outwards there is a gradual increase in the size of the hornblende crystals in successive bands, felspar and quartz become more abundant, and there is a gradual passage to a rather basic hornblendic granite of very variable composition. Sphene, as crystals up to 1·4 mm. in length, is often conspicuous in some of the hornblendic bands. A similar development of concentric bands rich in hornblende was described at a contact of quartz-diorite and pyroxene-granulite in the account of the metamorphic rocks.*

In many cases the original nucleus of the spheroid has disappeared, and its place is taken by a mass of hornblende and biotite forming an ellipsoidal nodular core to successive concentric shells. Some of these spheroids were 15 cm. in diameter and had weathered out whole from the enclosing granite. In other cases the spheroids are less clearly marked, and the orbicular structure is indicated only by slightly darker patches in the grey granite showing traces of radial and concentric lines of the dark minerals. The final stage is the complete obliteration of the orbicular structure and the development of a rather basic porphyritic hornblendic granite in patches of rather limited extent and very irregular distribution.

This hornblendic facies of the grey biotite-granite is a rather coarse-grained rock with granitic texture. It is very variable in composition. The hornblende is sometimes present as large black crystals, 1–2 cm. long, forming the centres of ill-defined orbicular structures: more frequently it is scattered through the rock rather

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* This report, No. 5, p. 137.

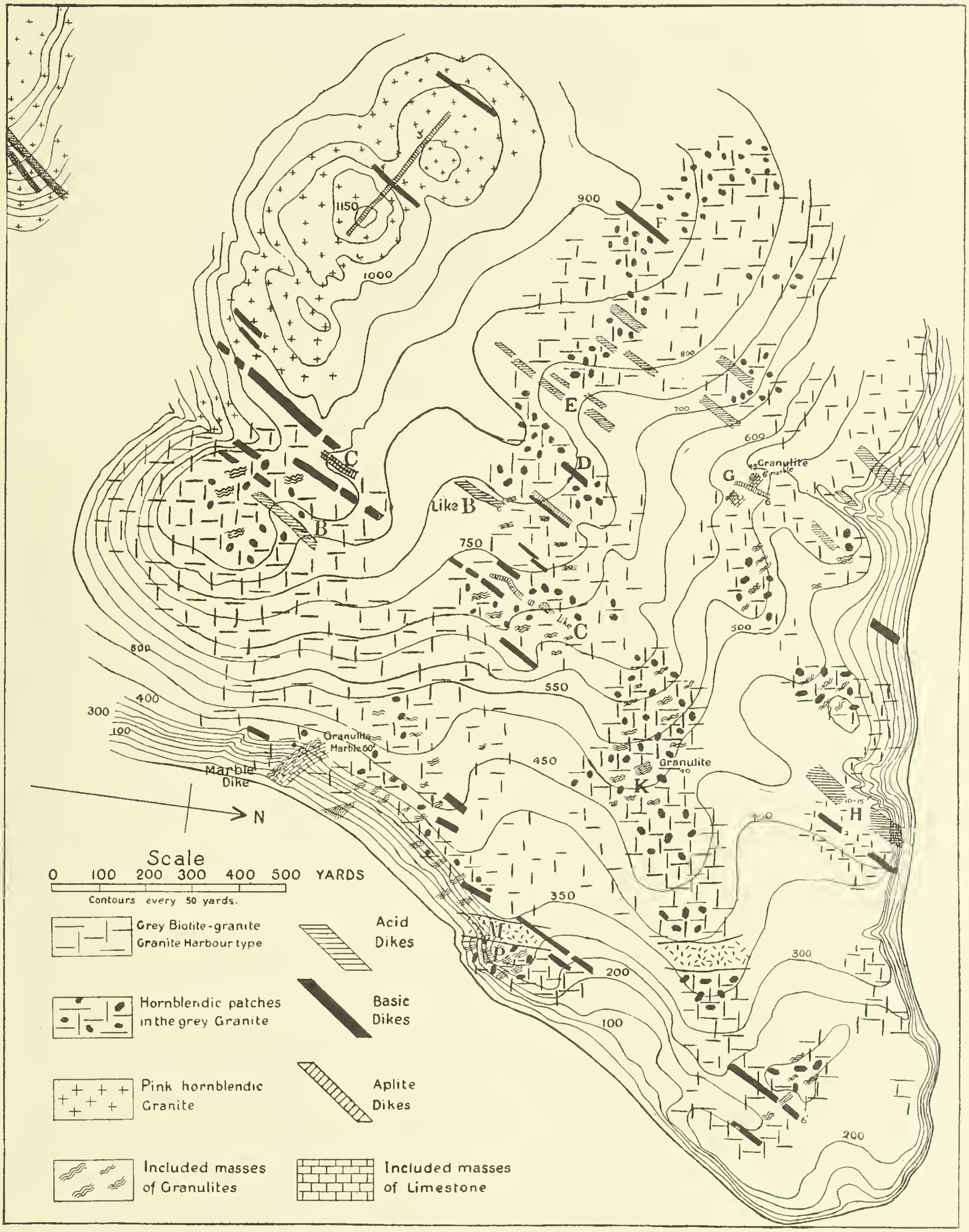

FIG. 4.—Geological sketch-map of The Flatiron, Granite Harbour. Based on the plane-table survey by Mr. F. Debenham.

unevenly as crystals up to 0·5 cm. across. There are a few porphyritic crystals of orthoclase up to 2 cm. long (Pl. 1, Fig. 4).

Under the microscope the rock is seen to consist of hornblende, orthoclase, oligoclase ($Ab_4 An_1$), and quartz, with some brown biotite: accessory constituents are apatite, orthite, and rather abundant sphene, sometimes as crystals 1 mm. long. The hornblende has the characters of common hornblende with pleochroism from pale yellow to dark shades of green.

A chemical analysis of one of the more even-grained specimens of this type (D90G) was made by Mr. J. B. Plattnauer with the results shown in Table II, column 3.

The norm calculated from this analysis is:—

Q	19·56	di	4·54
or	19·46	hy	8·70
ab	20·44	mt	3·25
an	21·41	il	1·37
		ap	0·34

The co-ordinates in the C. I. W. P. classification are II. 4. 3. 3.

In chemical composition the rock is not far removed from some of the quartz-monzonites of Butte, Montana, described by W. H. Weed.*

It is not intended in this place to discuss the chemical evidence in favour of the theory advanced that this basic hornblendic facies is due to the assimilation of para-pyroxene-granulites and possibly of limestones by the grey biotite-granite, but for convenience of future reference an analysis is given of a para-pyroxene-granulite from the core of one of the inclusions in the grey granite (D96G). This analysis has been made by Mr. E. D. Mountain of the Mineral Department, British Museum. The results are given in Table II, column 2, and for comparison an analysis by G. J. Burrows and E. B. Walkom of an acid pyroxene-granulite from an erratic at Cape Royds is given in column 1.

Whatever assimilation has gone on it clearly cannot be purely additive in character, for the hornblendic granite contains less silica than either the grey granite (Table II, column 4) or the pyroxene-granulite of the inclusion (Table II, column 2). The pyroxene-granulites themselves have a wide range of composition, and there is no means of ascertaining the exact composition of the inclusion before its envelopment by the invading granite. Quite apart from chemical evidence, however, the field observations point strongly to the development of the hornblendic facies by assimilation of included pyroxene-granulites. Every gradation can be traced from the orbicular granite to the basic hornblendic granite. Moreover Debenham has mapped in detail the distribution of the hornblendic granite on The Flatiron, and his mapping bears out his observations that this hornblendic facies occurs whenever inclusions of limestone and pyroxene-granulites are found (Fig. 4).

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* Weed (W. H.), U.S. Geol. Surv., Prof. Paper 74, 1912, p. 33. Washington (H. S.), U.S. Geol. Surv., Prof. Paper 99, 1917, p. 359.

The absorption of the metamorphic rocks must have taken place under deep-seated conditions while the granite magma was still fluid and yet too viscous to allow of the wide diffusion of the products of assimilation. The process was evidently completed before the extrusion of the acid apophyses which marked the final phase of the solidification of the grey granite, for these apophyses in places cut and metamorphose the hornblendic patches (see p. 181).

TABLE II.

	1.	2.	3.	4.
SiO_2	74·67	73·11	62·54	68·33
Al_2O_3	8·37	7·11	15·41	16·56
Fe_2O_3	0·95	0·26	2·21	0·34
FeO	3·37	3·45	4·18	2·82
MgO	2·52	3·48	2·53	0·61
CaO	5·19	6·06	5·60	3·43
Na_2O	2·09	1·89	2·39	3·98
K_2O	1·31	2·51	3·31	3·56
H_2O+	0·30	0·42	0·62	0·38
H_2O-	0·26	0·11	0·29	0·04
TiO_2	1·10	1·66	0·69	0·29
P_2O_5	0·57	tr.	0·25	0·23
MnO	0·09	—	tr.	tr.
	100·79	100·06	100·02	100·57

1. Erratic No. 96. Acid pyroxene-granulite (Para-pyroxene-granulite). Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), p. 161. Anal. Burrows (G. J.) and Walkom (A. B.).
2. D96G. Para-pyroxene-granulite from inclusion in grey granite: centre of spheroid. Anal. Mountain (E. D.).
3. D90G. Hornblendic facies of grey granite, The Flatiron, Granite Harbour. Analyst Plattnauer (J. B.).
4. D9G. Typical grey granite from Ridge Rocks, Cape Geology, Granite Harbour. Analyst Mountain (E. D.).

It is of interest to notice that two specimens (712 and 721) quite similar to the hornblendic facies of the grey granite just described were collected by Ferrar east of the shoulder E_2 at Cathedral Rocks, where "a tongue of granitic rock ends the gneissic exposure." The diorite (715) east of this tongue, described and analysed by Prior, is a more basic rock and quite distinct in character from the rocks we have been discussing. The occurrence of the hornblendic facies in the Ferrar Glacier region is additional evidence of the identity of the intrusions of grey granite here and in Granite Harbour.

Mention may be made here of some rocks (D104G, D84G, D56G) with the appearance of typical melanocratic *diorites* found in the talus below The Devil's Thumb ridge in the Devil's Punchbowl and on the slopes of Discovery Bluff. They are composed mainly of idiomorphic hornblendes and acid plagioclase with small patches of quartz and orthoclase. The hornblendes are present both as long prismatic and as tabular crystals. They give extinction angles of about 13°, and where they are unaltered the pleochroism is α cream-buff, β tawny- to buckthorn-brown, γ olive. There are abundant flakes of brown biotite in some specimens from the Devil's Punchbowl, and this has been partly altered into green chlorite; in most specimens the alteration is complete. The accessory constituents are sphene, epidote, and apatite, all abundant and the sphene particularly so.

These rocks are very similar in mineral composition to the sphene-bearing diorites of Mount Larsen described by Sir D. Mawson.* Unfortunately none of them were found in place.

Aplitic dikes and their effects on the xenoliths.

Dike rocks, which can be definitely associated with the grey biotite-granite, are very few. Red veins in the grey granite of Granite Harbour were observed by Ferrar,† who described their gradual passage from red at the centre of the vein to the normal grey granite. His observations have been confirmed by Debenham, who found these veins well developed on the western side of Cape Geology (D57G). Inclusions of metamorphic rocks were seen in the veins. As recorded by G. T. Prior ‡ the rock of these veins consists of coral-red phenocrysts of orthoclase (8 mm. × 5 mm.) in a ground-mass of drab-coloured oligoclase (ext. 12°) and quartz-mosaic with brown biotite. They are acid *orthoclase-porphyries* probably approximating in composition to the grey granite of which they are apophyses, and they are probably almost contemporaneous with its intrusion. They contain no hornblende and show no connexion with the pink hornblendic biotite-granite.

At the Devil's Punchbowl a coarse pegmatite (D11G) of quartz and coral-red orthoclase was found in which the crystals of orthoclase reach 7 cm. in length, and there are occasional plates of biotite 1·5 cm. in diameter. This differs in character from the pegmatites associated with the pink hornblendic granite described below (p. 185), and the fact that in one specimen the coarse pegmatite is in contact with one of the red veins just described indicates a possible connexion with the grey granite and not with the pink granite with which all the other pegmatites are clearly associated.

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* Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), pp. 224–5.

† Ferrar (H. T.), Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907), p. 33.

‡ Prior (G. T.), *ibid.*, p. 126.

Aplitic rocks found as erratics at Cape Bernacchi and Marble Point have been described in No. 5 of this report (p. 143), and it was there pointed out that these pyroxene-bearing aplites may be earlier than the grey granite of Granite Harbour. It is worthy of note, however, that somewhat similar aplites carrying pyroxene and scapolite, intrusive into or near calcareous sediments, are associated with the igneous complex of Phillipsburg Quadrangle, Montana,* one member of which has been shown to be closely related to the grey granite.

Other aplites were seen penetrating the granite at Cape Roberts, and at Point P on The Flatiron (Fig. 4), where Debenham observed a whole network of acid dikes cutting the granite and a large triangular patch of included metamorphics.

In one specimen (D96G) from Point K on The Flatiron an aplitic dike seems to have intersected and metamorphosed one of the patches of basic hornblendic granite. Near the contact the large black hornblende crystals are surrounded by pale green pyroxene in parallel position, and at four centimetres from the contact all trace of hornblende has disappeared and the resultant rock consists of large pale green diopsides (with included sphene), oligoclase-andesine, and subordinate quartz in patches of small rounded grains, with orthite and apatite as accessory constituents.

Rather similar diopside-bearing veins are found bordering the large inclusions of limestone at Marble Outcrop and Marble Dike described in No. 5 of this report (see Pl. 1, Figs. 5 and 6).

At Marble Outcrop the limestone is flanked by a para-pyroxene-granulite. An acid vein (D15G) in contact with this granulite consists of large crystals of orthoclase, with large green diopsides, 0·5–1 cm. across, patches of quartz, and abundant crystals of sphene 2–3 mm. in length. For about 0·5 cm. from the contact scapolite is developed in abundance and apparently replaces most of the felspar. The pyroxene-granulite also shows patches rich in scapolite in the neighbourhood of the contact.

At Marble Dike another similar acid vein (D14G) contains even larger diopsides which occasionally show relics of hornblende enclosed in the pyroxene. The felspar is mainly orthoclase. Sphene is rare, but both orthite and apatite occur as accessories.

These diopside-bearing acid veins appear to be due to assimilation by very acid intrusions of the metamorphic limestones and granulites and, in one case, to reaction with the hornblendic granite-patches. Similar rocks were found by the late Mr. A. F. Zealley in association with masses of limestone included in the granite of Donegal; and at Roiloup near St. Brévin (Loire-Inférieure), Professor Lacroix † has described the development of pyroxene (malacolite) and sphene in a "granulite" intrusive into a "gneiss pyroxénique à wernerite" (scapolite-bearing pyroxene-granulite). Here the intrusive "granulite" is composed of quartz and orthoclase in large crystals, and the crystals of pyroxene which are found up to 30 cm. from the contact reach as much as 3 cm. in length.

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* Emmons (W. H.) and Calkins (F. C.), U.S. Geol. Surv., Prof. Paper 78, 1913, p. 120.

† Lacroix (A.), Bull. Soc. franç. Min., 1889, vol. 12, p. 120.

Dr. C. E. Tilley * has recently indicated chemical conditions which may produce diopside-microcline rocks from impure dolomites in which he assumed sericite and quartz present as detrital minerals. In the present instance the quartz and orthoclase molecules have been supplied by the acid intrusion itself.

Acid dikes have penetrated the large inclusions of crystalline limestones and pyroxene-granulites at Marble Outcrop and Marble Dike and run roughly parallel to the foliation.† Near their contact with the pyroxene-granulites, the product (D85G) is a confused mass of garnet, actinolite, and idocrase, with some calcite and an indeterminate turbid matrix. At the actual junction (D7G) large ill-developed crystals of idocrase, green pyroxene, and wollastonite are the final products of the metamorphism.

Two of the acid veins within the mass of limestone at Marble Dike are shown in Pl. 1, Fig. 5. The centre of these veins consists of a very fine-grained, compact, pale grey rock (D23G) composed of abundant orthoclase or perthite with subordinate oligoclase and quartz, some colourless pyroxene, wollastonite, rose-red sphene in small crystals, occasional crystals of apatite, and some irregular patches of calcite. Towards the edges of the vein, scapolite appears forming large plates which enclose radiating clusters of wollastonite, some colourless pyroxene, and a little sphene and graphite. The dikes themselves are bordered by a selvage of fibrous wollastonite through which are scattered small green pyroxenes. The wollastonite is sometimes very strongly developed, forming large masses a foot or more across.

It is interesting to note that the aplitic veins alone appear to be responsible for the production of this marked contact metamorphism. No contact metamorphic minerals are found in the inclusions in the grey granite except where these have been cut by the aplitic dikes.

Pink Hornblendic Biotite-granite.

The pink hornblendic biotite-granite of Granite Harbour and the Ferrar Glacier region is quite similar to the pink granite of Cape Irizar described and figured by Sir Douglas Mawson ‡ and analysed by E. B. Walkom. The rock consists of flesh-coloured orthoclase, as Carlsbad twins rarely exceeding 1 cm. in length, with white oligoclase, dark blebs of quartz, and very small biotite flakes and hornblende prisms

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* Tilley (C. E.), Geol. Mag., 1920, vol. 57, p. 497.

† See this report, No. 5, p. 136.

‡ Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), p. 210.

in variable amount. The orthoclase crystals are conspicuous, owing rather to their colour than to any marked porphyritic habit. It is not necessary to repeat Mawson's account of the characters of the constituents. Allanite (orthite) was found as an accessory in all the typical specimens. The results of E. B. Walkom's analysis of the pink granite of Cape Irizar are given in Table III, column 2 (p. 197).

Granites with large red porphyritic felspars are recorded by Prior * from Granite Harbour, but the specimen (563) described from Snow Valley is exceptional in character and does not represent the general type. Other specimens of H. T. Ferrar's collection examined recently are found to show precisely the characters given by Mawson for the Cape Irizar type.

In Granite Harbour Debenham found the pink hornblendic granite forming Redcliffs,† the top of The Flatiron above the 1,000-foot contour, in the talus above Cape Geology, and *in situ* at the Devil's Punchbowl, where, as mentioned above, it comes down to the 300-foot contour. It evidently also forms part of Mount Suess and Gondola Ridge.

On the coast Priestley found it *in situ* at the western end of Gregory Island, and as erratics at Cape Roberts (2062), on the bluff between Cape Ross and Gregory Island (2082, 2088), and at Tripp Island (2080). David and Priestley have also described it at Cape Irizar, and the same rock probably forms Prior Island. The distribution of the pink granite is therefore very similar to that of the grey granite.

All the specimens of this granite collected by Ferrar have been carefully re-examined, and its known distribution in the Ferrar Glacier region is as follows:—

In the Kukri Hills, Hill D, at the western end, is of pink granite, and there seems no doubt that the wedge of granite extending from half-way up D to the top of D_2, as observed by Ferrar, is of the same kind. Debenham collected a specimen (D28F) above the dolerite in South American Glacier on Hill D. To the west, it probably forms one of the yellow bands seen at Solitary Rocks, and it was found as erratics at 4,000 feet on the side of Dry Valley below Beacon Heights (693). To the south, at Cathedral Rocks, it is found in the screes, but it is not known at what height it occurs, and Ferrar believed the light band above the dolerite to consist entirely of sandstone. Slightly farther to the east it was found at G_3‡ (557, 558) [*t* of Descent Pass, Map I], and at e_5 [the more western of the Granite Knolls, Map I], both at about 3,500 feet. A specimen (D3F) was collected by the present expedition in the talus of Double Curtain Glacier.

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* Prior (G. T.), Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907), p. 126.

† For illustration see No. 3 of this report, Fig. 5, p. 68.

‡ Ferrar's localities refer to the map of the district near the "Discovery" Winter Quarters, 1906, issued with Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907). Localities in square brackets refer to Mr. Debenham's map of the Ferrar-Koettlitz District, Map I, issued with this Number.

Such exposures as there are, therefore, indicate that the pink granite occurs as a thin sheet usually above the grey granite. At its best-known exposures in the Kukri Hills it is separated from both granite and overlying sandstone by sills of quartz-dolerite, and no junction of the two granites has been found at an accessible exposure. It is generally accepted that the pink granite is the newer, and some evidence in favour of this was given in the opening paragraph.

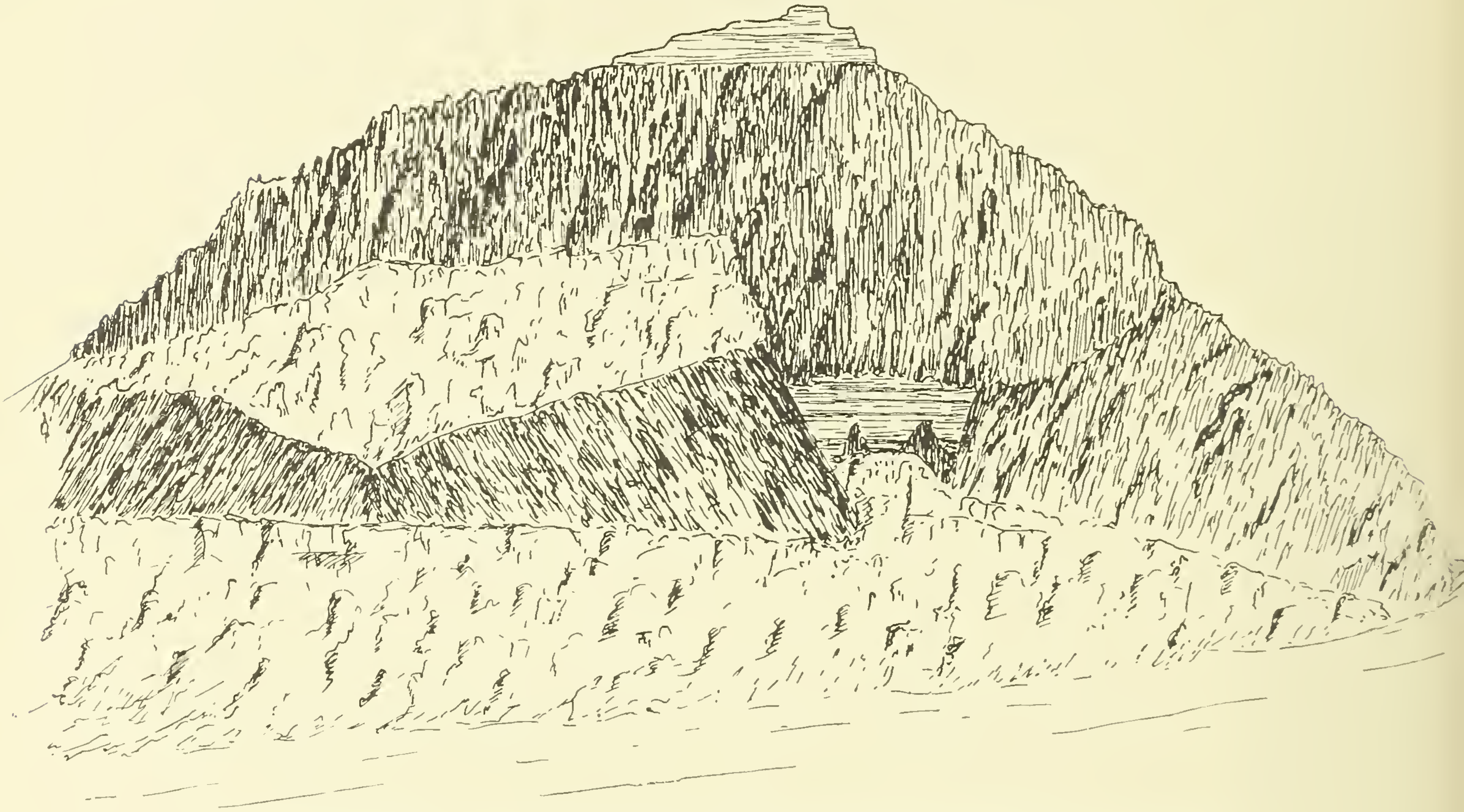

Fig. 5.—Triangular mass of the pink hornblendic biotite-granite enclosed in the dolerite sill, Point D, Kukri Hills, seen from the south. Sketched by Mr. F. Debenham.

Ferrar believed the pink granite to be intrusive into the quartz-dolerite and therefore later than the Beacon Sandstone. The geologists of the Shackleton Expedition (1907–9) and of the present expedition take the opposite view. Ferrar's belief was based on two facts: the occurrence in the granite of black patches which he believed to be fragments of dolerite; and a section at D in the Kukri Hills where he believed the granite was clearly intrusive into the dolerite.

Ferrar,* referring to his section at the western foot of D in the Kukri Hills as seen from the north and west, describes the pink granite as sending tongues into the columnar dolerite, "and the junction of the two was seen to be quite irregular." The specimens (699, 700) here referred to as showing the irregular junction are none other than the included black patches in the granite which G. T. Prior * described, and which he thought could only very doubtfully be regarded as altered dolerites. These specimens have now been re-examined. They certainly cannot be considered as altered fragments of dolerite, but seem to be lamprophyric segregations, with many features in common with the included patches of hornblende-lamprophyre in the porphyry of the Devil's Punchbowl. Clearly they cannot be regarded as evidence of the post-dolerite intrusion of the pink hornblendic granite.

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* Ferrar (H. T.), Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907), p. 36.

The other section mentioned by Ferrar as visible from the south showed three large irregular masses of light-coloured rock in the middle of a mass of dolerite which at this point is 2,000 feet thick. Debenham has visited this section and finds the triangular masses consist of pink granite apparently entirely surrounded and hoisted by the dolerite, and he thinks that conclusive evidence of the later intrusion of the dolerite is afforded by the fact that the columnar structure round the granite is developed with the columns everywhere at right angles to the junction surfaces (Fig. 5).

It seems most probable then that the pink hornblendic granite is earlier than the dolerite and earlier than the Beacon Sandstone, and it would be difficult indeed to explain its occurrence if it were otherwise. In the Ferrar Glacier region it appears to have been intruded between the top of the grey granite laccolite and its roof, forming only a thin sheet in the Kukri Hills. Later the whole composite laccolite seems to have been eroded, and the Beacon Sandstone has been deposited on its almost horizontal surface at about 3,000 feet above the present sea-level.

The subsequent intrusion of quartz-dolerite sills seems to have found two planes of weakness and has followed both, squeezing in between the grey and the pink granite as a lower sill, and at a higher level between the pink granite and the overlying Beacon Sandstone, so obliterating every natural junction of these rocks.

Many dikes and veins of pink aplite and pegmatite were observed cutting the pink granite at Cape Geology, Devil's Punchbowl, Gondola Ridge (NE. of Mount Suess), and Redcliffs. They vary considerably in grain from about 0·8 mm. to 2 or 3 cm., being usually coarser in the centres of the dikes and finer at the margins. They consist of quartz in graphic or micrographic intergrowth with flesh-coloured or buff orthoclase and white albite-oligoclase, with many long (2 cm.) narrow blades of drab-coloured biotite. Orthite as thin prisms (0·6 mm. × 0·06 mm.) is a rare but constant accessory. One of the finer grained types with porphyritic oligoclase was described and figured by Mawson.† These aplites and pegmatites were probably almost contemporaneous with the solidification of the pink granite.

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* Prior (G. T.), *ibid.*, p. 128.

† Mawson (D.), *loc. cit.*, p. 219 and Pl. III, Fig. 9.

HYPABYSSAL ROCKS.

Dikes from this region have been described previously by G. T. Prior,* who recorded camptonites, kersantites, and a banakite, and by Sir Douglas Mawson,† who described many porphyries which had not been recorded in Dr. Prior's report. Mr. Debenham has made observations on, and collected specimens of, many dikes both in the Ferrar Glacier region and in Granite Harbour. Their relations to other rocks are not always clear, but they are sometimes seen to cut the pink granite, as for example at the top of The Flatiron and at Devil's Punchbowl, and it is probable that all the dike rocks described here followed the intrusion of the pink hornblendic granite and are closely associated with it. They are all definitely later than the grey biotite-granite of Granite Harbour. In no case are they known to cut either the Beacon Sandstone or the later dolerite sills. Their chemical relations to the granites will be dealt with when similar rocks from Terra Nova Bay region are discussed later (p. 200). The general direction of all these dikes is NE.–SW., but there are two notable exceptions which will be mentioned below.

Porphyries.

Of the porphyries about to be described, four were collected in the Ferrar Glacier region, and the remainder in Granite Harbour, where they were found *in situ* at the spots indicated by letters on the maps (Figs. 2, 3, 4, and 6). They all appear from their mineral composition to belong to Rosenbusch's group of "granite-porphyry," that is to say they approximate in composition to granites.

Orthoclase and albite-oligoclase appear as phenocrysts in every case, orthoclase being dominant. Quartz, on the other hand, though abundant in all the dikes, appears as phenocrysts in only two types. These two will be spoken of as quartz-orthoclase-porphyries, the other types being described as orthoclase-porphyries with abundant quartz in the ground-mass.

Quartz-orthoclase-porphyries.

A typical quartz-orthoclase-porphyry is a red dike (D12G, D94G) exposed at C on The Flatiron.‡ It runs approximately SW.–NE. for about 50 yards and appears again 400 yards to the NE. A similar rock (D61G) cuts the pink hornblendic biotite-granite at Redcliffs (Fig. 2). In these rocks the phenocrysts consist of coral-red orthoclase (4 mm. long) and bi-pyramidal quartz (1–2 mm. diam.), with a few white crystals of albite-oligoclase. The ground-mass is about equal to the phenocrysts in amount, and consists of quartz and orthoclase with very little olive biotite, some green chlorite, and magnetite. In texture it is microcrystalline (0·04 mm. grain), becoming micrographic in some specimens. Orthite occurs as an accessory. This rock differs from all the other porphyries of the area in the entire absence of hornblende. An analysis of this rock (D12G) by Mr. E. D. Mountain is given in Table III, column 1.

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* Prior (G. T.), Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907), pp. 129–133.

† Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), p. 219, Pl. III, Fig. 9.

‡ Shown in Fig. 4 as an aplite dike.

The calculated norm is as follows:—

Q	31·38	di	1·46
or	24·46	hy	1·52
ab	37·73	mt	0·70
an	1·95	il	0·76

In the C. I. W. P. classification its symbol is I. 4. 1. 3 (4). Sub-rang Liparose.

Quartz-porphyries described by W. H. Weed and L. V. Pirsson, from Castle Mountain Mining District, Montana,* fall in the same sub-rang, but contain less SiO_2 and more Al_2O_3 and Fe_2O_3.

A rhyolite from Rimini, Butte District, Montana,† has a closely similar chemical composition, but contains 1·4 per cent. less Na_2O and nearly 1 per cent. more K_2O.

Rocks (2083, 2139) closely resembling the above, but with a drab or blackish brown cryptocrystalline ground-mass, were collected as erratics by Mr. Priestley on the island inshore of Depot Island, two miles north of Cape Ross.

The other quartz-orthoclase-porphyries contain slightly less quartz than the rock just described, and bottle-green hornblende appears in the ground-mass in addition to biotite. Orthite again appears as an accessory. The ground-mass (0·05 mm. grain) is not seen to develop micrographic intergrowths. In colour these rocks differ very markedly from the red dikes, the orthoclase phenocrysts being salmon-buff and the ground-mass smoke-grey in colour.

Rocks of this second type were found forming two widely separated dikes. One (D1F) in the hill at the base of Dry Valley Glacier, Ferrar Glacier region, forms part of a composite dike with a lamprophyric rock which is described below. The other (D103G) is a broad dike, in places 10 or 20 yards wide, running roughly east and west along nearly the whole length of Devil's Thumb ridge, at the Devil's Punchbowl (Fig. 3).

An analysis of this rock from near its contact with a lamprophyre dike at Z was made by Mr. J. B. Plattnauer, whose results are given in Table III, column 3.

The calculated norm is as follows:—

Q	25·20	di	1·89
or	25·02	hy	5·46
ab	27·25	mt	1·16
an	13·34	il	0·76

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* Weed (W. H.) and Pirsson (L. V.), U.S. Geol. Surv. Bull. 139, 1896, p. 99 and p. 103.

† Clarke (F. W.), U.S. Geol. Surv. Bull. 168, 1900, p. 119.

In the C. I. W. P. classification it falls in the sub-rang Toscanose, I. 4. 2. 3., where its high FeO and CaO distinguish it from most of the other rocks in the same sub-rang. Its chemical composition is quite close to that of the grey granite of Granite Harbour, quoted again for comparison in Table III, column 4.

At Z (Fig. 3) this quartz-porphyry dike is cut by a 12-foot dike of lamprophyre with the usual SW. to NE. trend. The relations of these two dikes were at first somewhat obscure, as the quartz-porphyry itself in its coarse-grained portions is full of inclusions of hornblende-lamprophyre similar to the rock forming the dike at Z. The two rocks seem to be very intimately associated. The dark patches in the porphyry frequently contain crystals of quartz, orthoclase, oligoclase, and biotite, which are sometimes gathered into patches several centimetres across. These crystals, averaging 2 mm. in diameter, are probably derived from the porphyry itself, but one large rounded crystal of orthoclase, 3 cm. long, appears similar to those seen in the granites.

Another interesting feature of this quartz-porphyry dike is the way it shows marginal modifications in which the ground-mass becomes darker (drab), almost cryptocrystalline in texture, and develops micropoikilitic growths of quartz.

The quartz patches here referred to as micropoikilitic are really of the same nature as those associated with certain spherulitic structures and described by A. Michel Lévy * as "structure globulaire," "sphérolites à quartz globulaire," and later as "structure sphérolitique avec globules imprégnés de quartz cristallisé." As G. H. Williams † excluded all these from the micropoikilitic structures because of their radial arrangement, perhaps some explanation of their description by that term is necessary.

The ground-mass of the fine-grained margin of the dike Z when viewed between crossed nicols is seen to break up into a number of round or oval spots, about 3 mm. or less in diameter, generally appearing lighter than the intervening ground-mass, but each one extinguishing quite sharply in a definite position. Besides the round spots, there are borders of exactly the same kind surrounding partly resorbed quartz phenocrysts and extinguishing in the same position as their nuclei. These borders are all of the same thickness (0·2 mm.). Under high magnification, the patches and borders are seen to consist of quartz grown outwards from a quartz nucleus, in optical continuity with this and enclosing short laths (0·04 mm. long) of orthoclase and a few flakes of biotite, without any regular arrangement, just as they occur in the ground-mass outside these patches. They have all the characters described

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* Lévy (A. Michel), Divers modes de structure des roches éruptives. Ann. des Mines. 1875, sér. 7, vol. 8, p. 376, Pl. X, Figs. 11, 12, and 13. Fouqué (F.) and Lévy (A. Michel), Minéralogie micrographique, 1879, p. 89. Lévy (A. Michel), Structures et classification des roches éruptives, 1889, p. 21.

† Williams (G. H.), On the use of the terms poikilitic and micropoikilitic in petrography. Journal of Geology, 1893, vol. 1, pp. 176–179.

by A. Michel Lévy in his "structure globulaire," except the radial arrangement which has been insisted on as an essential, and which caused G. H. Williams to differentiate between these structures and his micropoikilitic structures in which the included minerals "have no regular arrangement in respect either to one another or to their host." The question arises as to how far radial arrangement is always associated with growths of quartz in the ground-mass in this way. A. Michel Lévy certainly laid stress on its presence, but some of his figures show that it is not always prominent.* C. Barrois † described and figured a "porphyre globulaire" in which there was no trace of it, and G. H. Williams, ‡ describing a similar set of structures on a much smaller scale (0·04 mm.) in dikes at Tryberg in Schwarzwald, found radial structure frequent, but not always clear and sometimes absent. The case described above is another instance of the complete absence of the radial arrangement.

A. Michel Lévy was the first to give the explanation of the growth of these patches of quartz. Crystallization begins at a nucleus of quartz and proceeds outwards, wrapping round any previously crystallized minerals and developing micropoikilitic structure. Such growth in all probability is usually subsequent to the development of any spherulitic structures in the ground-mass. The frequent association of the two structures is probably indicative of the fact that certain conditions of composition of the final residuum of a solidifying acid porphyry, which at one stage in the cooling are favourable to the development of spherulites, are also favourable at a slightly later stage to the development of micropoikilitic quartz. The development of the two structures must be independent, and either may appear without the other. There seems, therefore, no reason for barring the use of the term micropoikilitic for the growths of quartz described above merely because it happens frequently that they have developed in a ground-mass with spherulitic structure.

Orthoclase-porphyries.

The orthoclase-porphyries with abundant quartz in the ground-mass vary slightly in texture and in the relative proportions of phenocrysts to ground-mass, but are singularly uniform in mineral composition. The phenocrysts are orthoclase, white to salmon-buff, 5 mm. or less in length, with oligoclase smaller and always subordinate. In one case (D68G) the orthoclase is perthitic and in places shows faint cross-hatching. The ground-mass consists of quartz, orthoclase, and oligoclase with a little biotite and green hornblende. Orthite is a constant accessory.

One exceptional dike at M (Fig. 4) on The Flatiron (D31G, D98G) is a pearl-grey rock with rather ill-defined phenocrysts. The ground-mass consists of subhedral crystals of orthoclase and oligoclase, about 1 mm. long, framed in patches of micrographic intergrowths of quartz with orthoclase, flakes of biotite, and prisms of hornblende up to 1 mm. in diameter. There are a few phenocrysts of biotite reaching 4 mm. in diameter. The rock might perhaps be described more correctly as a *granophyre*. Its exceptionally coarse-textured ground-mass is undoubtedly connected with the extraordinary thickness (150 feet) of the dike, which is further unusual in that it runs north and south and is itself cut by dark dikes running SW. to NE., the normal trend of all the other dikes in The Flatiron.

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* Lévy (A. Michel), Ann. des Mines, 1875, sér. 7, vol. 8, Pl. X, Fig. 13, Pl. XI, Fig. 2.

† Barrois (C.), Mém. Soc. Géol. du Nord, 1882, vol. 2, No. 1, p. 115, Pl. III, Fig. 2.

‡ Williams (G. H.), Neues Jahrbuch, Beil.Bd. II, 1883, pp. 605 *et seq.*, Pl. XII, Figs. 3 and 4.

The remaining rocks of this group are represented by four dikes, B (D95G), D (D99G), E (D68G), and H (D53G), all on The Flatiron (Fig. 4). They vary in colour from light mouse-grey (with phenocrysts about equal in amount to ground-mass), through drab, to pale chocolate. Phenocrysts are always less than 5 mm. (mediophyric), and in one case less than 1 mm. (minophyric). Their abundance relative to the ground-mass varies from sempatic (about equal in amount) in the paler varieties to quite rare (perpatic) in the darkest rocks. The ground-mass is microcrystalline varying in grain from 0·1 mm. to 0·02 mm., and in every case shows some development of micrographic patches usually framing the felspars. The hornblende and biotite are usually present as very small flakes, but show a marked tendency to form aggregates up to 1 mm. in diameter, often with grains of ilmenite and sometimes associated with sphene and zircon. In one case both minerals occur in long very thin wisps crossing the ground-mass in all directions, a habit which is associated with well-developed micrographic texture of the quartz and orthoclase. Two dikes of this group (D53G, D58G) show black or slate-blue margins in which the ground-mass is cryptocrystalline and is crowded with very small (0·008–0·004 mm.) microliths of hornblende and flakes of biotite. In the more fine-grained of these two (D58G) the hand-specimen shows flow-banding quite clearly.

Sir Douglas Mawson has described and figured* a black porphyry similar to one of the above, 8 miles south of Cape Irizar, and Mr. Priestley collected another example of it at Tripp Island (2078).

Three specimens collected in the Dry Valley area are hornblende- and augite-bearing orthoclase-porphyries of less acid character than those described above, and oligoclase is more abundant. One from the moraines below the Riegel (D7F) and another from the debris below Cheyenne Crater are identical with the orthoclase-porphyry figured and described by Mawson.† The third, very similar in composition, was found *in situ* at the top of the hill on the south side of Suess Glacier. These contain abundant cream-coloured or pale pink orthoclase, 1·5 cm. long, and smaller white crystals of oligoclase and black (γ olive-green) hornblende (up to 7 mm. long) evenly distributed. There are some rare phenocrysts of augite almost completely uralitized. Biotite is abundant as very small (0·5 mm.) flakes. The ground-mass is less abundant than the phenocrysts and varies from drab-grey to olive-grey in colour. It consists of quartz and orthoclase with hornblende or biotite or both, the grain-size varying from 0·2 to 0·04 mm. In some cases the quartz is in micrographic intergrowth with orthoclase, surrounding small crystals of the latter mineral.

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* Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), p. 216, Pl. II, Fig. 4.

† *Ibid.*, p. 217, Pl. II, Fig. 2.

Several fragments of a light neutral-grey felsite showing a few small phenocrysts of felspar were collected by Priestley from the island next to Depot Island. They are probably similar to those described by Mawson [*] as of the hälleflinta type and as comparable to the pre-Cambrian porphyries of South Australia.

Lamprophyres.

These are fairly widely distributed in the McMurdo Sound region, and some of them form composite dikes with the quartz-orthoclase-porphyries described above. Camptonites and kersantites have been described already by Prior [†] and Mawson. [‡]

Hornblende-lamprophyres.

One type different from any described hitherto is an *augite-bearing vogesite* (D26G), found in the debris above Cape Geology. It is very fine-grained, with smoke-grey ground in which patches of myrtle-green are evenly distributed at 2–3 mm. intervals. It consists of phenocrysts of colourless augite ($\gamma : c = 41°$) and patches of pale green serpentine in a ground-mass of laths of felspar and idiomorphic brown hornblendes (0·1 mm. thick). There is no certain indication of the origin of the serpentine. The hornblende gave $\gamma = \beta$ medal-bronze, α clay-colour, $\gamma : c = 10°$. Part at any rate of the felspar is plagioclase, but orthoclase is abundant and fills the interstices between the plagioclase laths.

A similar rock (D4F) but rather altered was found *in situ* at Double Curtain Glacier. Both rocks compare rather closely with the augite-vogesite of Mittershausen in Hesse.

Rocks similar to all the types described by Prior as *camptonites* are represented in the collection. One very similar to his figured specimen [§] (839) was found as an erratic at Tripp Island, the specimen showing it to be in contact with a green, very felspathic grit or tuff of doubtful origin and age. Another (D20G) from Cuff Cape is a very fine-grained camptonite similar to Prior's 498. It consists of small brown prisms of hornblende (1·2 mm. × 0·15 mm.), sometimes with skeletal development, in a fine-grained (0·02 mm.) dense ground-mass of plagioclase and brown hornblende. The pleochroism of the hornblende is γ Dresden-brown, α light buff to very pale yellow. A biotite-rich type is a fine-grained blackish slate-coloured rock forming a dike near Cape Geology.

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[*] Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), p. 217.

[†] Prior (G. T.), Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907), pp. 129–131.

[‡] Mawson (D.), *loc. cit.*, pp. 220–222.

[§] Prior (G. T.), *loc. cit.*, Pl. IX, Fig. 5.

Most of the other specimens are similar to Prior's second type.* One of them (D103G) cutting the big quartz-porphyry dike at Z, Devil's Punchbowl (Fig. 3), is a very fine-grained, dull greenish-black rock, and consists of idiomorphic, long, brown hornblendes (0·02 mm. thick) and some irregular patches of pale uralitic hornblende, in a ground-mass of lath-shaped crystals of felspar, mostly oligoclase (0·04 mm. thick), and a little quartz. The hornblendes are very numerous and occupy about 50 per cent. of the rock. The crystals gave $\gamma : c = 14°$; pleochroism α pale orange-yellow, β Brussels-brown, γ deep Brussels-brown.

Other specimens of the same type were found at the west end of Gregory Island (2092, 2096), and in the talus on the north side of the lakes below Suess Glacier, Dry Valley (D13F). Some of them contain a little biotite.

An analysis by Mr. J. B. Plattnauer of the dike Z, made on material taken near the contact, is given in Table III, column 8. As far as any judgement can be based on the few published analyses of hornblende-lamprophyres, the composition of this one is nearer to that of the *spessartites* than to the camptonites, most of the latter containing less SiO_2 and usually higher CaO and alkalies. The calculated norm is :—

Q	0·0	il	1·22	di	7·71
or	7·23	mt	5·57	hy	23·71
ab	27·25	ap	1·34	ol	2·70
an	18·90				

and the rock falls in the sub-rang Camptonose, III. 5. 3. 4., which includes many analyses of basalt and "diabase," but curiously enough no analysis of a camptonite is found in it among the superior analyses.

In the presence of so much water in the rock analysed, its calculated position in the C. I. W. P. classification may be abnormal. Certainly when its composition is compared with those of the other analysed dike rocks whose analyses are plotted in Fig. 9, it is seen that this rock (D103G) occupies a very abnormal position, having a remarkably high content of magnesia and unusually low alumina and alkalies.

In these hornblende-lamprophyres abundant xenocrysts give rise to patches of rock of quite peculiar composition. It appears from an examination of the specimen (720) referred by Dr. Prior † to banakite that it is actually a hornblende-lamprophyre with abundant xenocrysts. His specimen (714), which he analysed (Table III, column 9) and described as banakite, is a rock of entirely different character, but this too has a composition which is abnormal when compared with the other dike rocks of the district (Fig. 9).

What appears to be a new type comes from one of the dikes (D20G) at the eastern end of Cuff Cape, where glacial striae on the outcrop of the dikes are indicated on the map (Fig. 6). This is a compact aphanitic rock, blackish-slate in colour. With a lens, very small needles of hornblende, 1–2 mm. long, can be seen evenly distributed through the rock. Under the microscope it is seen to consist of rather abundant small phenocrysts of brown hornblende and very few microphenocrysts of andesine, in a very fine-grained ground-mass (0·006 mm.) of plagioclase (andesine), brown hornblende, and biotite. The texture of the ground-mass is panidiomorphic-granular (Fig. 7), with rather marked parallel arrangement of the constituents.

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* Prior (G. T.), *loc. cit.*, p. 129.

† *Ibid.*, p. 131.

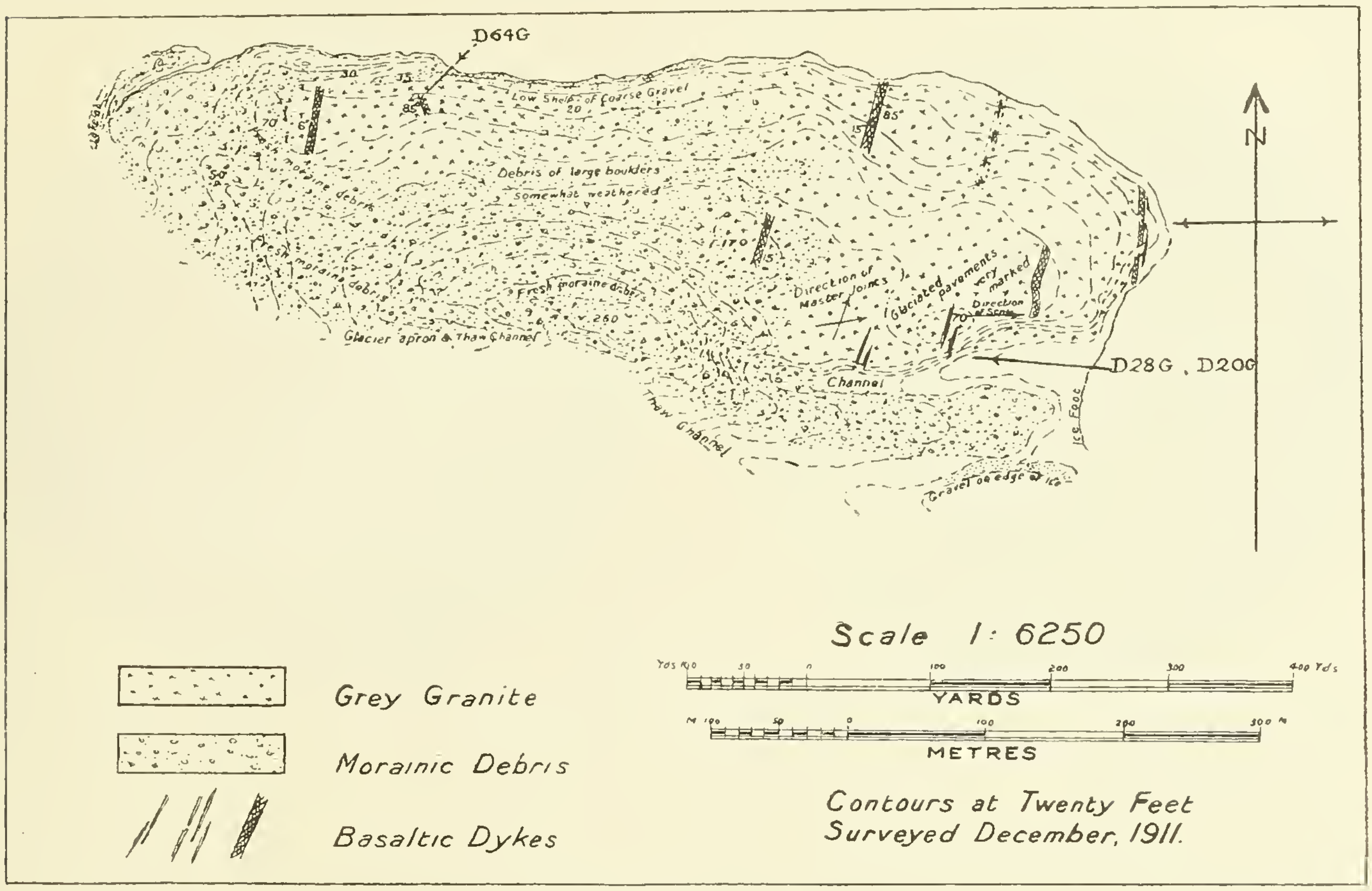

FIG. 6.—Cuff Cape, Granite Harbour. From the plane-table survey by Mr. F. Debenham.

The plagioclase of the microphenocrysts was determined as andesine ($Ab_{54} An_{46}$). The hornblende is in long thin prisms, 0·1–0·2 mm. thick, and the ends of the prisms are often hollow (skeletal development); $c : \gamma = 14\frac{1}{2}°$; pleochroism $\gamma = \beta$ tawny-olive, α light buff with sometimes green shades on the outer margins. In the ground-mass the hornblende is in very minute prisms, and there are very abundant minute flakes of brown biotite. It is very difficult to distinguish the biotite from the hornblende, on account both of the similarity in pleochroism and of the extremely small size of the flakes, but biotite appears to be the main dark constituent of the ground-mass. The felspar in the ground-mass could not be determined with certainty, but much of it appears to consist of minute laths of plagioclase. No orthoclase was detected. Small patches of free quartz were observed, but it is possible that their introduction is due to secondary causes.

Two analyses of the rock were made by Mr. E. D. Mountain, and the mean of his results are given in Table III, column 5. The rock falls on the boundary between the sub-rangs Shoshonose and Andose II. 5 3. (3) 4. in the C. I. W. P. classification with the following norm :—

Q	8·82	di	3·68
or	16·12	hy	12·60
ab	28·82	mt	0·93
an	26·13	il	2·28

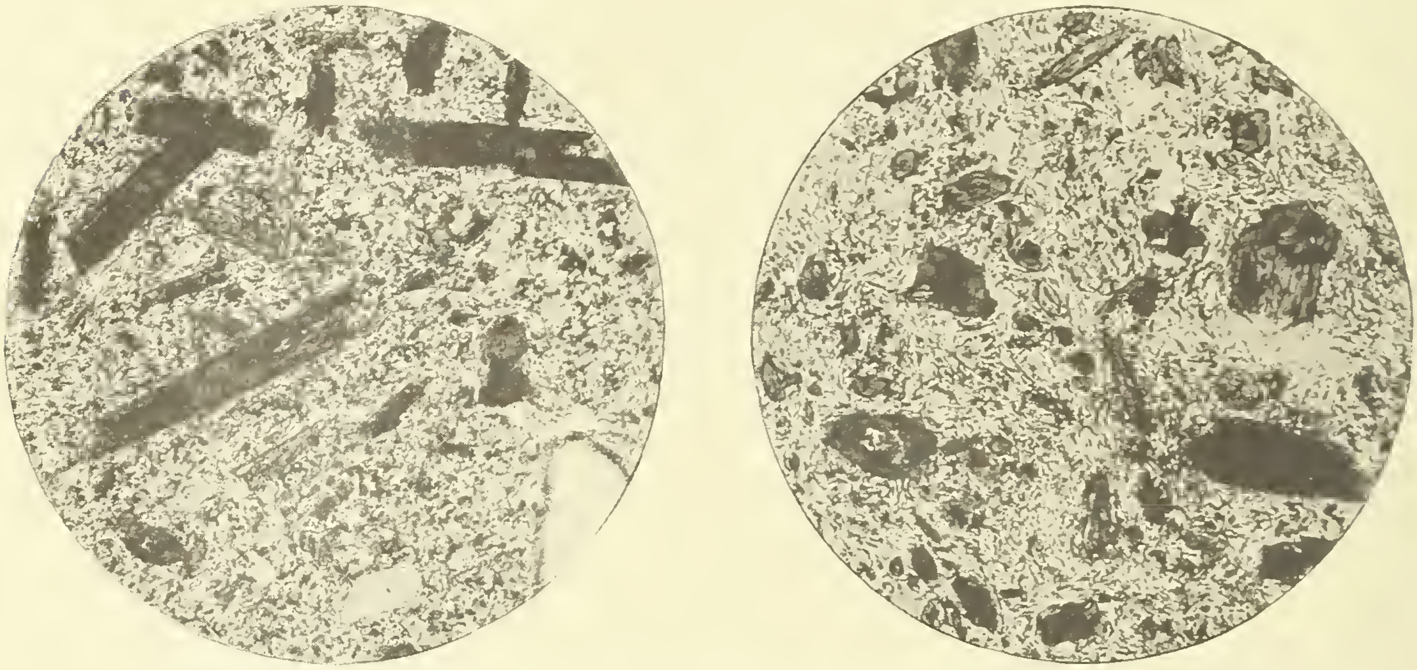

Fig. 7.—Hornblende-lamprophyre (Cuff Cape type), east end of Cuff Cape, Granite Harbour (D 20 G). Photomicrographs of thin sections taken in two planes at right angles to one another. Magnification 30 diameters.

No close comparisons can be made with published analyses, and it does not appear that any similar rocks have been described. Its character is that of the lamprophyric rocks, and although few of these contain as much as 59 per cent. SiO_2. the new type may provisionally be described as *hornblende-lamprophyre* (Cuff Cape type).

Mica-lamprophyres.

Augite-biotite-kersantite closely related to the rocks described by Prior [*] and Mawson [†] is found forming a composite dike (D1F) with the quartz-orthoclase-porphyry in the basalt-capped hill at the base of Dry Valley Glacier, Ferrar Glacier region. The porphyry dike is flanked on both sides by the kersantite, and there seems to be some symmetrical variation in the character of the lamprophyre from the centre outwards, but the specimens collected do not allow of any details being made out. The colour of the lamprophyre varies from speckled olive-grey to almost black, or red when weathered. The rocks consist of very small phenocrysts (< 5 mm.) of oligoclase-andesine, augite, and biotite, in a ground-mass of laths of oligoclase, orthoclase, biotite (and chlorite) with quartz. The ferro-magnesian constituents are more abundant in the darker varieties, and this is probably accompanied by increasing content of plagioclase. The augite is nearly colourless or very pale buff and is always bordered by pale green uralite.

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[*] Prior (G. T.), *loc. cit.*, p. 130.

[†] Mawson (D.), *loc. cit.*, pp. 220, 221.

As in the case of the quartz-porphyry dike at the Devil's Punchbowl, so here the porphyry contains dark inclusions which on examination prove to be patches of the kersantite, rather fine-grained but closely similar to the lamprophyre in the dike itself.

Compared with the type analysed by Prior, this dike has apparently a higher content of quartz. In many respects it is comparable with the "kersantite-quartzifère récente compacte" from Asturias described and figured by C. Barrois,* rocks which Rosenbusch has classed with his "Dioritporphyrit."

The rocks collected by Ferrar from G_4 and e_6 (Granite Knolls) in the Ferrar Glacier region, and described by Prior under the heading of banakite, seem to be altered examples of the type just described in which all the biotite has altered to chlorite. These rocks were intrusive in the crystalline limestone at G_4 and in the grey granite at e_6.

Other augite-biotite-kersantites, quite devoid of phenocrysts and corresponding still more closely than the above to Prior's type (579), form dikes on The Flatiron (D105G and D40G), at Cape Geology (D27G), at Discovery Bluff (D75G), and half-way up the slope of Cuff Cape (D64G). The plagioclase laths give symmetrical extinctions up to 25° corresponding to andesine ($Ab_{57}\ An_{43}$). Augite gives pleochroism $\alpha = \gamma$ pale greyish vinaceous, β pale olive-buff, $c : \gamma = 36°$. The grain-size is about 1 mm. and the texture in places becomes doleritic. Occasionally there are small interstitial patches of micrographic intergrowths of quartz and orthoclase. The 18-inch dike at Cuff Cape (D64G) contains included fragments of biotite-granite and of limestone, the latter itself probably derived from one of the inclusions in the grey granite. The inclusions of granite are partially absorbed.

Porphyrites.

Various basic dikes having small phenocrysts (0·8 mm.) of andesine-labradorite and augite in a ground-mass (0·02–0·04 mm. grain) of plagioclase (oligoclase) and biotite with a little magnetite, though slightly more basic, are no doubt closely allied to the augite-biotite-kersantites described above. Rocks of this kind are *in situ* at

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* Barrois (C.), Mém. Soc. Géol. du Nord, 1882, vol. 2, p. 148, Pl. I, Fig. 1.

Gondola Ridge (D72G), a dike on The Flatiron (D49G), and dikes at Cuff Cape (D34G) near the eastern end showing ice-worn surfaces (Fig. 6).

A *biotite-porphyrite* (D28G) presenting more distinctive characters is from the "twin diorite dikes" at the east end of Cuff Cape. This is almost black, with scattered white or pale pea-green phenocrysts (4–5 mm. long) of andesine-labradorite, brown biotite (1–2 mm.), and a few of colourless augite, in a ground-mass (grain 0·04 mm.) of laths of felspar, shreds of brown biotite, green hornblende, and some quartz. The ground-mass is abundant (dopatic). Orthoclase is abundant and clearly-twinned felspar in the ground-mass is not conspicuous. The most striking feature about the ground-mass is the wisp-like appearance of the hornblende and biotite, like crystallites in a glass (Fig. 8). The biotite in these rocks gives pleochroism $\beta = \gamma$ sepia, α pale primrose-yellow: it is particularly full of inclusions of magnetite arranged parallel to the cleavage planes. The colourless augite has always a green uralitized border, and some patches of hornblende and biotite are believed to be pseudomorphs after augite. A quite similar rock (D39G) forms another dike on The Flatiron. This contains a few phenocrysts of hornblende as well as biotite, and also shows many rounded crystals of quartz and felspar which have the appearance of xenocrysts. The quartzes are sometimes surrounded by little patches of micrographic intergrowths of quartz and orthoclase.

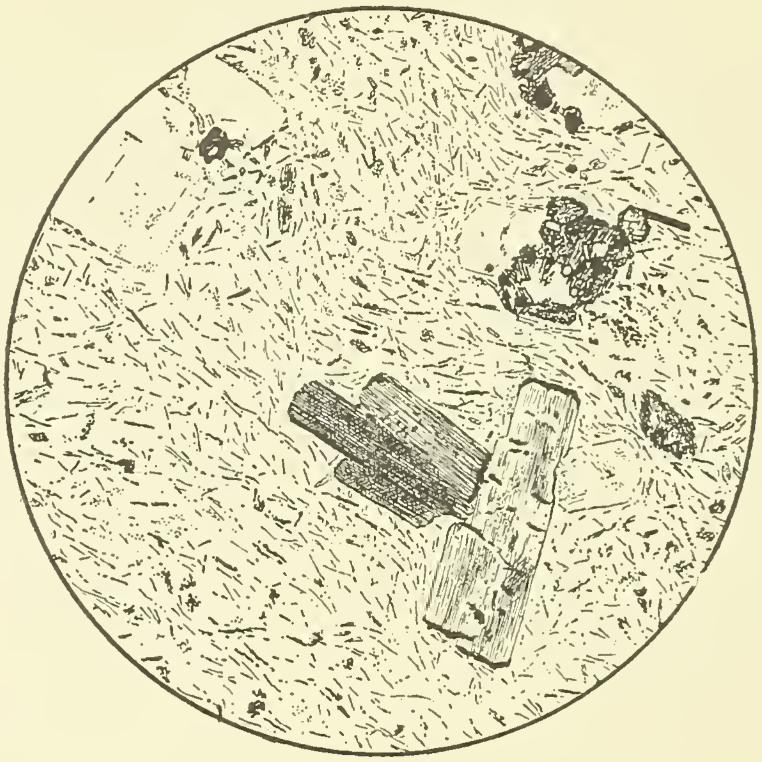

Fig. 8.—Biotite-porphyrite (D 28 G) dike, east end of Cuff Cape, Granite Harbour, McMurdo Sound. Magnification 15 diameters.

Another dike rock from Cuff Cape (D73G) is probably allied to the above, but is entirely free from phenocrysts and consists of laths of plagioclase with orthoclase and some quartz, and minute flakes of hornblende and biotite, the grain averaging 0·04 mm., and the colourless constituents forming about 85 per cent. of the rock.

TABLE III.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
SiO_2	75·45	71·87	69·62	68·33	58·93	53·06	50·71	49·58	48·22
Al_2O_3	12·53	15·16	14·80	16·56	18·16	18·65	17·08	13·58	18·47
Fe_2O_3	0·45	0·62	0·84	0·34	0·64	1·44	1·38	3·93	5·28
FeO	1·67	2·10	3·02	2·82	5·18	7·58	8·71	8·28	3·90
MgO	0·14	0·29	0·89	0·61	2·92	3·78	3·63	7·54	2·07
CaO	0·70	0·84	3·14	3·43	6·14	8·22	5·75	6·10	6·02
Na_2O	4·43	3·88	3·19	3·85	3·42	3·20	3·82	3·22	4·94
K_2O	4·12	4·72	4·21	3·56	2·74	1·55	3·63	1·25	3·47
H_2O+	0·29	0·35	0·23	0·38	0·56	0·94	1·75	4·05*	4·12*
H_2O-	0·17	0·15	0·09	0·04	0·10	0·16	0·16	1·09	0·44
TiO_2	0·37	0·25	0·45	0·29	1·25	1·60	2·71	0·60	2·09
P_2O_5	—	tr.	tr.	0·23	—	0·38	0·57	0·54	0·88
MnO	—	0·04	tr.	tr.	0·07	0·05	0·09	0·41	0·10
	100·32	100·27	100·48	100·44	100·11	100·61	99·99	100·17	100·00

1. D12G. Quartz-orthoclase-porphyry, Dike C, The Flatiron, Granite Harbour. Anal. E. D. Mountain.
2. Hornblendic biotite-granite, Cape Irizar, South Victoria Land. Anal. A. B. Walkom (Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), p. 211).
3. D103G. Quartz-orthoclase-porphyry, dike, Devil's Punchbowl, Granite Harbour. Anal. J. B. Plattnauer.
4. D9G. Grey biotite-granite (Hornblende-free granodiorite), Granite Harbour. Anal. E. D. Mountain.
5. D20G. Hornblende-lamprophyre (Cuff Cape type), dike, eastern end Cuff Cape, Granite Harbour. Anal. E. D. Mountain.
6. 715. Basic diorite, Cathedral Rocks, Ferrar Glacier region. Anal. G. T. Prior (Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907), p. 127).
7. 579. Augite-biotite-kersantite, G_1, Ferrar Glacier region. Anal. G. T. Prior (Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907), p. 130).
8. D103G. Hornblende-lamprophyre (Spessartite), Dike Z, Cuff Cape, Granite Harbour. Anal. J. B. Plattnauer. * H_2O+ includes 0·22 % CO_2.
9. Banakite, G_5, Ferrar Glacier region. Anal. G. T. Prior (*loc. cit.*, *supra*, p. 132). *H_2O+ includes 1·23 % CO_2+ loss.

Quartz-dolerites.

In Number 4 of this report,* which deals with the sedimentary rocks of South Victoria Land, frequent references were made to the dolerite sills intrusive into the Beacon Sandstone which are known to occur over an enormous extent of the Antarctic continent from Adelie Land, lat. 58° S., long. 150° E., to the Beardmore Glacier, lat. 85° S. These rocks are quartz-dolerites, frequently enstatite-bearing. They have been fully described by G. T. Prior,† W. N. Benson,‡ and more recently by W. R. Browne,§ and there is nothing fresh to add to the observations of those authors. Debenham collected specimens from sills *in situ* at two localities in the Ferrar Glacier region, viz. D6F beneath basalt in a hill at the base of Dry Valley Glacier, and D29F below pink granite in South American Glacier below Hill D: in both places the olivine-bearing type described by Prior was present, as well as the more normal enstatite-bearing quartz-dolerite of the Knob Head type. In Granite Harbour, specimens (D69G, D106G) were collected on Mount Suess and Gondola Ridge, *in situ* at both places, and also as erratics (D80G, D93G, D108G). Priestley found them as erratics (2044, 2071, 2093, 2094, 2098) at Gregory Island, Tripp Island, and Marble Point. Some of the specimens (D108G) from the Gondola moraine show on weathered surfaces very beautiful stellate groups of the curiously elongated pyroxene crystals mentioned by W. R. Browne.‖ Some of these pyroxenes are 1½ inches long.

Prior and Benson have pointed out the close similarity between these quartz-dolerites and widespread intrusions of late Mesozoic and probably Cretaceous age in Natal,** Brazil, British Guiana, and particularly in Tasmania.†† The resemblance with the Tasmanian dolerites is so close that Benson suggested a similar, Cretaceous, age for the dolerites of South Victoria Land. The only facts bearing upon their age which have been obtained hitherto from field evidence are that the dolerites are later than the Beacon Sandstone, i. e. post-Gondwana, and earlier than the recent volcanics.

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* For figures showing dolerite sills see this report, No. 4, Figs. 1, 2, 5, 6, 7.

† Prior (G. T.), Nat. Ant. Exp., 1901–4, Natural History, vol. 1 (1907), pp. 136–139.

‡ Benson (W. N.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), pp. 153–160.

§ Browne (W. R.), Australasian Ant. Exp., 1911–14, Sci. Rep., ser. A, vol. 3, Geology, part 3 (1923), pp. 245–258.

‖ *Ibid.*, p. 251.

** Prior (G. T.), Ann. Natal Museum, 1910, vol. 2, part 2, p. 151.

†† Benson (W. N.), *loc. cit.*, pp. 159–160.

THE TERRA NOVA BAY REGION.*

Our knowledge of the nature of the plutonic and hypabyssal rocks of the Terra Nova Bay region is derived from specimens collected in three areas, each of which seems to contain a slightly different assemblage of rocks. These three sources of information are:

1. Erratics collected on Evans Coves Beach.
2. Rocks found *in situ* in the northern half of Inexpressible Island, in Vegetation Island, and in the Northern Foothills, and the erratics of Hell's Gate moraine.
3. Rocks, chiefly erratics, collected in the moraines of the Boomerang, Campbell, Corner, and Priestley Glaciers. (See Map II in folder.)

ERRATICS FROM EVANS COVES BEACH.

Among the erratics from Evans Coves Beach are several types of rocks similar to those described from Granite Harbour. They are not represented among the rocks found north of Inexpressible Island (except by a single boulder from the Northern Foothills), and it is probable that they are derived from the Mount Larsen area or from the foothills between Reeves Glacier and Priestley Glacier. Somewhere in this area there must be an intrusive mass of granite similar to and possibly a continuation of the Granite Harbour intrusion.

Granites and associated dike rocks.

Mawson † has already described the grey biotite-granite of Mount Larsen, and Edgeworth David ‡ has described a grey granite, probably the same as that of Mount Larsen, forming Mounts Gerlache and Crummer. This granite differs from the Granite Harbour type in the almost total absence of orthoclase, but in other respects the two seem closely similar, and it is significant that at Evans Coves we find erratics which seem to belong to both types. Various specimens (1347, 1468, 1473, 1535) were found which seem to correspond exactly with Mawson's description of the Mount Larsen type, and one erratic from the Northern Foothills (1426) presents the same characters and contains numerous inclusions of biotite-schist. In these rocks orthoclase is remarkably rare. Several other erratics (1346, 2023) correspond exactly with the Granite Harbour type as described above and contain pale pink orthoclase phenocrysts 4 cm. long. One of these was collected from a moraine which reaches the sea about 17 miles south of Evans Coves, and it probably had been carried from the Larsen-Crummer massif between the Reeves and Priestley Glaciers. Like the Granite Harbour rocks they show well-developed mortar-structure. The pink hornblendic biotite-granite (Cape Irizar type) was not found.

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* Based on the specimens collected and field-notes supplied by Mr. R. E. Priestley, geologist on the Expedition.

† Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), p. 212.

‡ David (T. W. E.) and Priestley (R. E.), *ibid.*, vol. 1 (1914), p. 48.

Dike rocks which are comparable with those found intrusive in the biotite-granites in Granite Harbour are not numerously represented. A pink millimetre-grained *aplite*, consisting mainly of albite-oligoclase and quartz, with very little orthoclase and a little biotite and sphene, is probably connected with these granites. A few specimens of coarse *pegmatite* occur, and in one case a pegmatite vein is seen intruding a granite (foliated) of Mount Larsen type (1473).

Of the more basic dikes, two specimens (1518,1883) are *augite-bearing vogesites*, having a fine-grained ground-mass and containing a rather pale-coloured hornblende (β gold-yellow, α cream-buff) but in other respects similar to the vogesite from Cape Geology (p. 191). Three other aphanitic dull green rocks (1519, 1539, 1882) with indefinite pale patches have been referred to *spessartite*. These consist of numerous slender prisms (0·06 mm. across) of rather pale brown hornblende with a little magnetite, in a ground-mass of felspar, most of which is plagioclase. Some quartz is present. They are much less melanocratic than the camptonites, but they are much altered and contain a good deal of epidote and other secondary products.

From the general character of these erratics and of the granite and dike rocks described by Mawson from this area, it seems fairly certain that in the neighbourhood of Mount Larsen there is a recurrence of the igneous complex of pre-Beacon Sandstone age which is found in Granite Harbour and the Ferrar Glacier region. Mawson * has published a number of analyses by Mr. A. B. Walkom of the rocks from Mount Larsen, and these are shown in Table IV together with three analyses of rocks from Cape Irizar on the coast about 50 miles to the south.

The analyses are too few to enable a reliable variation-diagram to be constructed, but, to facilitate the comparison of the rocks of Terra Nova Bay region with those of McMurdo Sound, the percentages of the principal oxides have been plotted against silica percentages (Fig. 9). The analysis of the Mount Larsen granite shows low K_2O and high FeO compared with the quartz-porphyry from Granite Harbour of almost the same silica percentage. The other analyses form a fairly continuous series, with the exception of the hornblende-lamprophyre (D103G) and the banakite at the basic end of the series (see p. 192). The Cape Irizar granite shows a rather high content of total alkalies, and the granite-porphyry of Cape Irizar shows high Na_2O and low K_2O, but its percentage of total alkalies is almost exactly that of the Mount Larsen quartz-porphyry. Unfortunately no analysis of the pink hornblendic biotite-granite of Granite Harbour is available, so that the identity of this rock with that of Cape Irizar cannot be finally proved, though from Mawson's description of his rock this identity seems extremely probable.

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* Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), pp. 209-227.

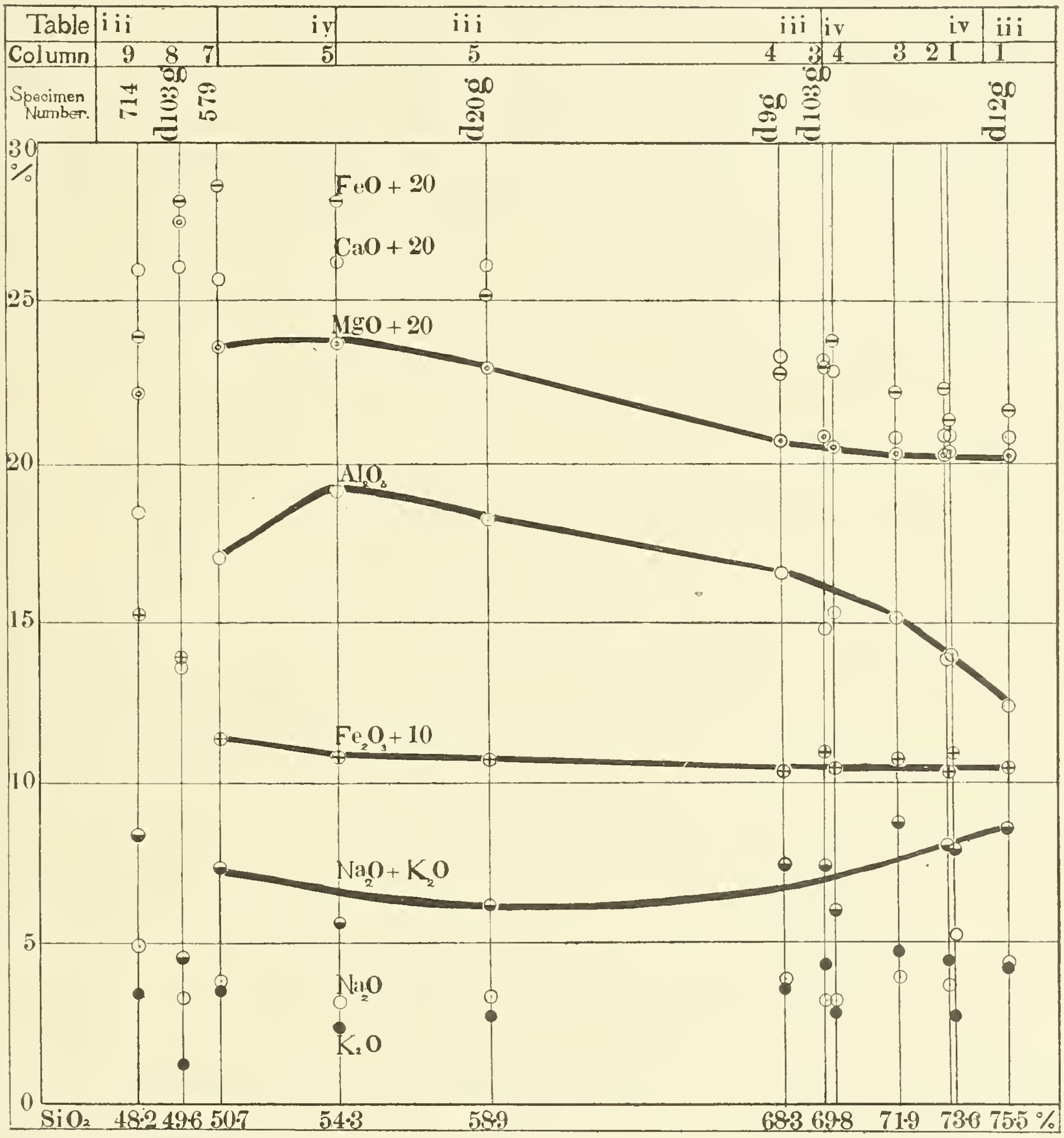

Fig. 9.—Variation-diagram of some of the granites and dike rocks of South Victoria Land.

TABLE IV.

	1.	2.	3.	4.	5.	6.	7.
SiO_2	73·64	73·55	71·87	69·85	54·27	51·91	51·35
Al_2O_3	13·93	13·70	15·16	15·35	19·23	20·75	18·90
Fe_2O_3	0·90	0·24	0·62	0·40	0·73	1·08	2·03
FeO	1·40	2·36	2·10	3·88	8·29	7·32	7·87
MgO	0·30	0·26	0·29	0·52	3·74	3·05	3·30
CaO	0·96	0·92	0·84	2·94	6·41	7·07	8·81
Na_2O	5·17	3·59	3·88	3·13	3·05	3·04	3·73
K_2O	2·73	4·46	4·72	2·87	2·49	2·44	1·48
$H_2O +$	0·47	0·36*	0·35	0·24*	0·77*	0·58	0·97
$H_2O -$	0·16	0·08	0·15	0·03	0·18	0·04	0·09
TiO_2	0·33	0·21	0·25	0·36	1·33	2·34	0·79
P_2O_5	—	—	tr.	0·50	—	0·52	0·57
MnO	tr.	0·05	0·04	0·06	—	—	—
CO_2	—	0·04	0·09	0·01	0·05	0·11	0·01
	99·99	99·82	100·36	100·14	100·54	100·25	99·90

1. Aplitic granite-porphyry, Cape Irizar (I. 4. 2. 4).
2. Quartz-porphyry, near Mt. Larsen (I.″ 4. (1) 2. 3).
3. Hornblende-biotite-granite, Cape Irizar (I. 4. 1. 3).
4. Biotite-granite, Mt. Larsen (I. 4. 3. 3).
5. Kersantite, Cape Irizar (II. 5. 3″. (3) 4).
6. Sphene-biotite-hornblende-diorite, near Mt. Larsen (II. 5. 3 (4). (3) 4).
7. Biotite-hornblende-diorite, near Mt. Larsen (II. 5. 3″. 4).

Enstatite-peridotite.

Two boulders (1406, 1415) from the Northern Foothills, dull greenish-black rocks with large plates of hornblende and biotite, prove to be an *enstatite-peridotite* rather resembling the rocks described as "harzburgite" by G. P. Merrill * from Montana and by Whitman Cross † from Custer Co., Colorado.

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* Merrill (G. P.), Proc. U.S. Nat. Mus., 1895, vol. 17, p. 655.

† Cross (C. W.), Proc. Colorado Sci. Soc., 1887, vol. 2, p. 240.

The main constituents are olivine and enstatite in grains 1–2 mm. diam., but both brown hornblende and amber-brown biotite are present in large flakes up to 2 cm. across. Labradorite is present in small amount either enclosed by the enstatite or as interstitial grains. The only accessory constituents are magnetite and apatite, both rather scarce. The enstatite is pleochroic from very pale buff-pink to faint green: its amount in relation to the olivine varies considerably in different sections. The hornblende of the large crystals is brown (α tawny, γ ochraceous-tawny) and gives an extinction angle of 20°. At the edges of the large crystals it often shades off to a pale pea-green colour, and in other parts of the section there is much hornblende, sometimes surrounding enstatite, and varying in colour from dark bluish-glaucous to pea-green. The biotite when unaltered is amber-brown in thin section but it too is seen to pass into a pale green variety. This enstatite-peridotite is of particular interest as it is the only ultra-basic eruptive rock recorded from South Victoria Land. The other rocks from Evans Coves are such as are found either *in situ* near the coast or in the moraines of the glaciers to the north.

ROCKS FOUND *IN SITU* NEAR EVANS COVES, AND ERRATICS FROM HELL'S GATE MORAINE.

The Northern Foothills, Vegetation Island, and the northern half of Inexpressible Island consist of a mass of granitic rocks apparently intrusive into, and interpenetrating in a most complicated manner, fine-grained rocks of dioritic composition and doubtful origin. In many places there are definite intrusions, dikes and veins, of acid in the more basic rocks. Elsewhere the granites predominate but are full of numerous inclusions of the dioritic rocks, and often there is an appearance in such places as of basic intrusions in the granite mass. Frequent inclusion of masses of metamorphic gneisses and schists by some of the granites adds still further to the perplexing character of the rocks exposed in this area.

The general appearance of these rocks in the field is well described in the following extract from Mr. Priestley's field-notes taken at the time :—

"The rock consists of a grey granite with veins, inclusions, and large masses of a more basic rock. This rock is so fine-grained that it weathers first to a shale and then to a fine dust, while the granite weathers by a shelling process which results in the formation, first of a nucleus of rock more or less spherical in shape, according as the jointing is cubical or rectangular, and finally to a coarse arkose-grit."

"The principal contrast of weathering is seen where the veins and irregular masses of fine-grained rock occur. As these disintegrate much more rapidly than the granite they produce depressions in the general level which—in the case of veins occurring on the side of a hill—resemble well-made roads. Everywhere else the rock has the characteristic boulder-strewn appearance of a typical granite country, except where the less common aplitic veins stand out like the corded veins of a flexed human arm."

"Where the larger masses of basic rocks impinge on the granite the two rocks are so veined and included in each other that it is sometimes difficult to realize that one is not dealing with a complex of schists and gneisses."

"Pegmatite veins are common and these, weathering quickly, give rise to streams of quartz fragments which at first sight were very puzzling, giving the impression that erratics occurred right up to the top of the hills. I was, however, later able to see distinctly how these streams were formed and should be inclined to attribute similar streams of blackish and greenish, fine-grained, rounded, and sub-angular fragments to the occurrence of similar quick-weathering of basic veins. Inclusions of many varieties of schists and gneisses are common. Amongst these was a coarse biotite-rock occurring as a circular inclusion some 20 to 30 yards in diameter."

Diorite [Northern Foothills Type].

The dark dioritic rocks of this complex are represented by numerous specimens from the whole of the area now being considered. The majority of these are compact, aphanitic, dark purplish-grey rocks with small lustrous patches of hornblende. In very many of the hand-specimens there are veinlets of pegmatite, aplite, or micro-granites penetrating the dark rock, and several fine specimens from Hell's Gate moraine show the dioritic rock so intimately permeated by microgranite that the whole presents the appearance of a very coarse breccia (Fig. 10). Slightly less abundant are specimens of fine-grained speckled rocks in which white felspar, flakes of dark brown biotite, and sometimes hornblende are clearly distinguishable in the hand-specimens. These too are seen to be penetrated by pegmatitic veins. Both these types have the mineralogical composition of *biotite-diorites* with small amounts of free quartz and containing variable quantities of hornblende, and all are characterized by an exceptional abundance of colourless sphene usually closely associated with magnetite (or ilmenite). The aphanitic rocks, averaging 0·2 mm. in grain, consist of short laths of oligoclase with very abundant brown biotite in small flakes, varying amounts of pale green hornblende (pistachio-green), quartz, and very scarce orthoclase. Crystals of orthite are seen in some sections. Sphene and a black iron oxide, some pyrrhotite, and small apatite needles are all very abundant. The sphene is colourless and occurs sometimes in small irregular grains or strings of grains but very frequently it forms colourless mantles to grains or rods of the iron oxide which are themselves enclosed in the biotite flakes (Fig. 11).

The speckled rocks of coarser grain (1 to 2 mm.) seem to have the same mineral composition as the aphanitic rocks. All the constituents mentioned above are present. The grain-size varies from 1 to 2 mm., with occasional crystals of biotite or felspar reaching 5 mm. in diameter. Some of the larger oligoclase crystals contain

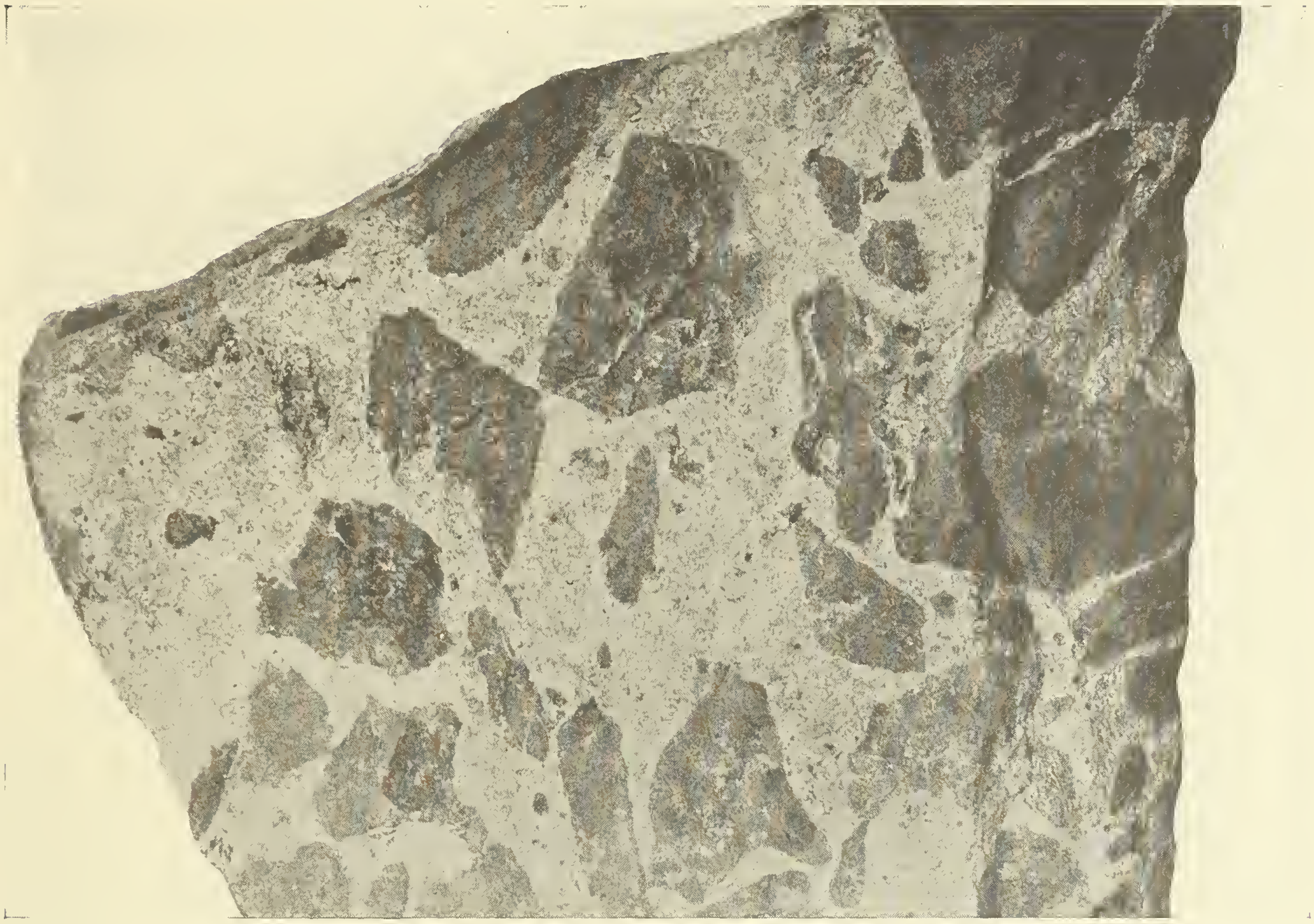

Fig. 10.—Diorite intruded by microgranite. Erratic (1967) from Hell's Gate moraine, Terra Nova Bay region.

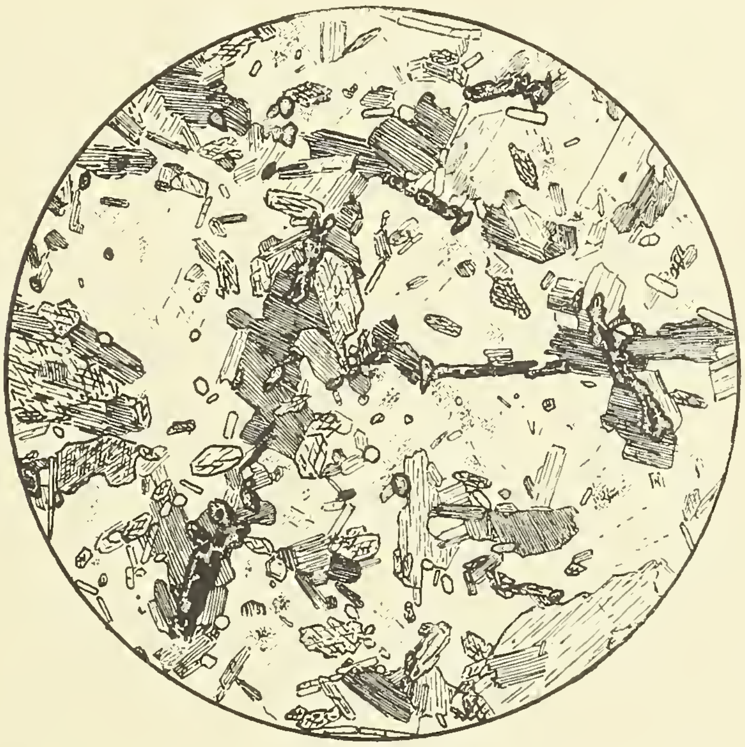

Fig. 11.—Biotite-diorite (1967), Hell's Gate moraine, Terra Nova Bay region.

zones of small flakes of biotite, and show rather rounded outlines which may be indicative of resorption. The biotite (hazel to maize-yellow) is very fresh and well-developed, and its inclusions of grains of iron oxide with their mantles of quite colourless sphene are very conspicuous. Small needles of apatite are very abundant and are found penetrating all the principal constituents. The hornblende is very variable in amount and irregular in distribution: in one specimen (1590) the quantity present is very small indeed. It occurs either as aggregates of small prisms or as irregular crystals, and is nearly always closely associated with the biotite by which it is sometimes partially enclosed: in such cases grains of quartz separate the hornblende and biotite. It has very much the appearance of being a product of secondary crystallization. Its pleochroism is: α olive-buff, β asphodel-green, γ pistachio-green. $c : \gamma = 15°$.

An analysis of a typical specimen of the fine-grained variety from Hell's Gate moraine (1967) has been made by Mr. E. D. Mountain, whose results are given in Table V, column 1, where they are compared with the analysis of a quartz-augite-diorite dike in gneiss, east of Lampersdorf, Silesia.[*]

In the C.I.W.P. classification the rock falls in the sub-rang Andose "II. 5. 3."4, the calculated norm and an approximate estimate of the mode being as follows:—

Norm.				*Approximate Mode.*			
Q	4·02	hy	10·23	Quartz	2	Hornblende	17
or	15·57	di	12·90	Orthoclase	4	Biotite	23
ab	28·82	il	2·58	Albite	29	Sphene	3
an	23·07	ap	0·67	Anorthite	20	Magnetite	1·5
		mt	1·62				

Prior's "diorite" from Cathedral Rocks and Mawson's sphene-bearing diorites from Mount Larsen fall in the same sub-rang but are all much poorer in SiO_2. Compared with the rocks of about the same silica-content in the Mount Larsen-Granite Harbour series, this diorite is markedly poor in magnesia and alumina and richer in lime.

The name biotite-diorite, which is here applied to these rocks, seems fairly to indicate their mineral and chemical composition, but little light has been thrown on their history. It seems quite possible that they may belong to the same set of intrusions as the dark dioritic rocks which Edgeworth David [†] observed, penetrated by a greyish granite at the southern slope of Mount Crummer, representatives of which were described by Mawson. [‡]

Some of the characters of the diorites of the Northern Foothills, notably the

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[*] Dathe (E.), Jahrb. K. Pr. geol. Landesanst. für 1886, 1887, p. 331.

[†] David (T. W. E.) and Priestley (R. E.), Brit. Ant. Exp., 1907–9, Geology, vol. 1 (1914), p. 245.

[‡] Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), pp. 224–225.

TABLE V.

	1.	2.	3.	4.	5.	6.
SiO_2	55·63	55·54	71·55	71·27	71·51	71·19
Al_2O_3	16·92	15·64	13·41	13·40	13·82	14·01
Fe_2O_3	1·10	1·19	1·60	1·11	1·76	1·66
FeO	7·70	7·13	1·26	1·89	1·20	1·29
MgO	2 34	4·84	0·64	0·79	0·80	0·44
CaO	8·03	5·67	2·46	2·46	1·79	2·04
Na_2O	3·41	3·17	3·46	3·08	3·64	3·56
K_2O	2·61	2·28	4·84	4·91	4·63	4·45
H_2O+	0·46	2·93	0·15	0·18	0·31	0·33
H_2O-	0·15		0·40	0·32	0·17	0·04
TiO_2	1·33	1·24	0·21	0·24	0·33	0·35
P_2O_5	0·27	—	0·08	0·10	0·30	0·34
MnO	0·11	—	tr.	0·07	0·03	0·02
S	0·08	—	—	CO_2 0·03 Cl 0·06 (Ni,Co)O 0·01	—	—
	100·14	99·63	100·06	99·92	100·29	99·72

1. 1967. Biotite-diorite, erratic from Hell's Gate moraine, Terra Nova Bay region, South Victoria Land. Anal. E. D. Mountain.
2. Quartz-augite-diorite, dike in gneiss, East of Lampersdorf, Silesia. Anal. W. Hampe [Dathe (E.). Jahrb. K. Pr. geol. Landesanst. für 1886, 1887, p. 331].
3. 1967. Biotite-microgranite, intrusive in biotite-diorite, erratic from Hell's Gate moraine, Terra Nova Bay region, South Victoria Land. Anal. J. B. Plattnauer.
4. Typical 'Tingha' granite, Tingha, New South Wales. Anal. W. A. Greig [Carne (J. E.), N.S.W. Dept. of Mines, Min. Res., No. 14, 1911, p. 64].
5. Medium-textured medium-grey biotite-granite, Petersburg, Dinwiddie Co., Virginia, U.S.A. Anal. W. M. Thornton [Watson (T. L.), U.S. Geol. Surv. Bull. 426, 1910, p. 72].
6. Fine-grained dark blue-grey biotite-granite, near Richmond, Virginia, U.S.A. *Ibid.*

abundance of sphene and its habit and mode of occurrence, recall features shown by some of the so-called " basic patches " of certain well-known British granites, and rather close comparisons can be made with some of the fine-grained patches in the Newry granite in Castlewellan quarry, Co. Down. Mawson * considered that the features exhibited by the diorites from the Mount Larsen area were suggestive of lamprophyric segregations.

In the Northern Foothills, however, the diorites occur on such a scale that it is difficult to think of them as segregations, and it seems probable that the characters which have suggested their origin as such are contact metamorphic phenomena induced by the granite which invades them and seems to permeate their whole mass. It is, however, interesting to note that segregations of dioritic rocks on a very large scale have been described in some granites from northern New South Wales (see p. 209).

Biotite-granite [Northern Foothills type].

The rocks which intrude these dioritic rocks are biotite-granites, poor in biotite, varying in grain from a porphyritic variety with white felspar phenocrysts a centimetre long, through even-grained varieties, to a fine-grained microgranite at actual contacts with the dioritic rocks. Many of the granites are stained pink, and in some the quartz crystals are coloured deep-red (neutral red), and so give the rock a rather unusual appearance. The microgranite is pale grey.

These granites and microgranites are represented by twenty-four specimens showing many variations in grain and various degrees of admixture with the dioritic rocks. They seem to be uniformly distributed and it is not possible to show that any particular variety is limited to any one of the localities. Porphyritic types appear at Vegetation Island (1598) and Northern Foothills (1411) ; even-grained rocks (2 mm. grain) seem to be well represented both at Vegetation Island (1601) and at Inexpressible Island (1878) ; and the pale grey microgranite is most abundant at Hell's Gate moraine, where very fine large specimens, showing the brecciation and intrusion of the dioritic rocks, were collected.

Mineralogically, all these specimens appear to belong to one intrusion of biotite-granite. They are characterized by an abundance of microcline, whereby they are sharply distinguished from the Granite Harbour and Mount Larsen types described above.

The porphyritic variety contains white phenocrysts of microcline, 1 cm. long by 0·4 cm. wide, about equal in volume to the ground-mass, which is equigranular, about 2 mm. in average grain-size, and consists of quartz, albite-oligoclase, and biotite. The biotite is not very abundant ; in different specimens its colour by transmitted light varies from dark olive to chestnut-brown : alteration to chlorite was observed in several sections. The accessory constituents include sphene, zircon, orthite, magnetite, and apatite. Sphene is the most characteristic of all these, and is present in nearly every slide examined. It is quite easily observable in many of the hand-specimens under a lens as honey-yellow crystals up to 1 mm. long and usually closely associated with the biotite. In thin section it is a pale pinkish-cinnamon in colour. It often contains small inclusions of magnetite or ilmenite. Orthite occurs in two of the slides (1598 and 1411), and is there seen as good idiomorphic crystals 0·8 mm. long: in one slide they are surrounded by colourless epidote. Zircon and apatite, and sometimes magnetite, all occur as inclusions in the biotite, the first being present in every slide, often in well-formed crystals.

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* Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), p. 226.

The non-porphyritic granite has an average grain-size of about 2 mm. Its constitution is precisely similar to that of the porphyritic rock described above, except that no orthite has been seen in any of the sections.

The pale grey microgranite differs only in texture from the granites. It is a millimetre-grained rock containing a few small phenocrysts, up to 2 mm. long, of albite-oligoclase, in a ground-mass of quartz and microcline with very small flakes of dark olive biotite. Sphene is present in every section examined. Orthite was only found in a specimen (1594) from Vegetation Is., which showed the red-stained quartz grains already mentioned as of frequent occurrence in the orthite-bearing granites of the area.

A sample of this microgranite intrusive in the diorite in an erratic (1967) from Hell's Gate moraine was carefully freed from included patches and specks of diorite, and an analysis was made by Mr. J. B. Plattnauer whose results are given in Table V, column 3. This falls in the sub-rang Toscanose, I. 4. 2. 3, the calculated norm being:—

Q	27·0	di	4·86
or	28·36	hy	1·16
ab	29·34	hm	1·60
an	6·67	il	0·46

Compared with the pink granite of Cape Irizar, it contains less Al_2O_3 but more Fe_2O_3, and is lower in FeO and richer in CaO. The percentages of SiO_2 and alkalies present in the two rocks are remarkably close.

The sub-rang Toscanose contains analyses of several granites which come very close to the Northern Foothills type, and three of these are quoted in columns 4, 5, and 6 of Table V.

The comparison with the "Tingha" granite of the New South Wales tin-fields is very interesting, as there is much in common between the igneous rocks of South Victoria Land and those described by E. C. Andrews * from northern New England.

Thus, in New South Wales there is a series of granite intrusions of two or three

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* Andrews (E. C.). Rec. Geol. Surv. N.S.W., 1905, vol. 8, p. 114.

different types intruded in Permo-carboniferous rocks along a roughly north and south line for about 100 miles. In the north of the area there is a sphene-granite-porphyry with a remarkable development of basic segregations of dioritic rocks "at times of such an extent as to suggest . . . the presence of totally differing rock-types," and offering many points of resemblance with the dark dioritic rocks of the Northern Foothills just described.

Wherever collected the microgranite was full of the fragments of dioritic rocks which it had intruded and brecciated. Very occasionally it contains round white patches of coarse-grained granite. The explanation of such patches is possibly indicated by a specimen (1471) of a fine-grained granite in contact with the dioritic rock. For several millimetres from the contact the granite becomes noticeably coarse in grain, and the dark minerals, if not less abundant, are, at any rate, less uniformly distributed than in the fine-grained granite away from the contact. Such coarse-grained patches, formed on the walls of the intrusion or surrounding included masses, might be torn away and carried along as the intrusion proceeded, their angles and edges being rounded by partial re-solution in the magma.

The specimen just mentioned as showing this contact effect on the texture has also characters indicating that the granite undergoes some change in constitution at its contact with the dioritic rocks. At 8 or 10 cm. from the contact it is a fine-grained biotite-granite, but within a centimetre of the junction where the grain becomes coarser it is found that stumpy prisms, 0·3 mm. thick, of bottle-green hornblende are well-developed and are often closely associated with the biotite. Microcline is still the predominant felspar in this contact-granite: the plagioclase is oligoclase giving an extinction angle of 7°.

Hornblendic Biotite-granite.

Hornblende, closely associated with the biotite, is found in a very striking pale cream-coloured granite from Hell's Gate moraine. The rock is spotted with black patches, half a centimetre across, which consist of very dark biotite often associated with very dark green hornblende in crystals up to a millimetre in length. The pleochroism of these minerals is: biotite, α mustard-yellow, $\beta = \gamma$ olivaceous-black; hornblende, $\alpha = \beta$ ivy-green, γ = dull blackish-green.

The ground-mass consists of quartz and felspar with microcline clearly predominant over albite-oligoclase. There are a few subhedral Carlsbad twins of microcline, 0·5–1 cm. long, but the average grain-size is between 2 and 3 mm. Neither apatite nor sphene was observed in this rock, but orthite is remarkably abundant, especially as inclusions in the large biotite flakes. One flake of biotite contains as many as ten crystals of orthite about 0·1 mm. long. Magnetite and zircon both occur as inclusions in the biotite. Small crystals of zircon are also enclosed by the orthite.

It is not known whether this rock is really associated with the other biotite-granites of the neighbourhood as it is only represented by three erratics from one moraine.

Aplites and Pegmatites.

Aplites, rich in microcline and sometimes containing garnet, are represented by a number of specimens. In one from Inexpressible Island (1869) the red garnets reach as much as a centimetre in diameter, and muscovite is present as well as biotite.

A pale grey aplite, sometimes containing very small pink garnets, is represented by about a dozen specimens mostly from the Northern Foothills. The quartz in this rock forms graphic intergrowths with the felspar. Some specimens (1470) show more coarse-grained veins, which also contain garnet and muscovite and must be very similar to the erratic (No. 566) from Cape Royds described by W. G. Woolnough * as pegmatite, and also to the garnetiferous aplite found as a boulder at Cape Adare by Borchgrevink and described by Prior. †

A single specimen of tourmaline-bearing aplite was collected in the Northern Foothills (1405). Its relations to the other rocks are not known, but it is mentioned here on account of the exceptional character of the tourmaline. It is a very fine-grained (0·5 mm.) rock, pale buff in colour, with minute black prisms of tourmaline, up to 2 mm. long and about 0·2 mm. thick, scattered through it. In thin section the tourmalines appear a most beautiful blue colour with pleochroism : α pale lilac, γ dark dull violet-blue. The rock consists of quartz, microcline, and albite-oligoclase, with very small plates of muscovite and no biotite.

Pegmatites, except as veins in the aplites, are represented by only one specimen intrusive in dioritic rocks at Inexpressible Island and by a few fragments of pegmatite or clear crystalline quartz from Evans Coves or Vegetation Island.

ROCKS, CHIEFLY ERRATICS, FROM THE BOOMERANG, CAMPBELL, CORNER, AND PRIESTLEY GLACIERS.

Granites, aplites, pegmatites, and diorites are all represented in the erratics from the moraines of the four glaciers to the north of Evans Coves, and they afford some indication of the northward extension of the plutonic complex which has just been described.

There seems to be an extension of the granites and diorites of the Northern Foothills across the Campbell Glacier, at least as far as the second bend of the

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* Woolnough (W. G.), Brit. Ant. Exp., 1907–9, Geology, vol. 2 (1916), p. 169.

† Prior (G. T.), Report on the Collections of Natural History made in the Antarctic Regions during the voyage of the "Southern Cross", London, 1902, p. 323.

Boomerang Glacier reached by Priestley, Abbot, and Browning on January 20th, 1912, and Priestley believes the ridge above the Campbell Glacier is also of granite.

The specimens collected *in situ* here were an even-grained (5 mm.) biotite-microcline-granite (1898) and three specimens of dioritic rocks clearly related to the dioritic rocks of Northern Foothills.

Several more specimens of dioritic rocks were collected from the Boomerang-Campbell moraine (1280, 1291), and from round the nunatak of schist and gneiss at the entrance to Boomerang Glacier.

Some of these rocks differ from the diorites described from the Northern Foothills as they are richer in hornblende and much poorer in biotite and quartz, and the felspar seems to be more basic ($Ab_1\ An_1$) than in the diorites from the other localities. Most of the rocks are even-grained (2 mm.), but some contain coarser patches in which the biotite and felspar are very conspicuous, and apatite, always an abundant accessory, occasionally forms prisms 1 mm. across and several millimetres long. Another marked difference between these rocks and those of the Northern Foothills is the abundance of magnetite and almost complete absence of sphene. The hornblende in one specimen (1628) shows very abundant "schiller" inclusions. Three rocks (1773, 1776, 1780), basic diorites, from the west moraine of the Campbell Glacier below its junction with the Boomerang Glacier are probably related to these last, but are still richer in ferro-magnesian constituents and contain very little felspar (near $Ab_1\ An_1$). There may be some connexion between these rather basic diorites and the enstatite-peridotite erratic described above (p. 202).

Other rocks from the Boomerang-Campbell moraine are aplites and pegmatites similar to some described from the Northern Foothills, but there are also specimens of biotite-granite of rather a different type.

In No. 5 of this report * a detailed description was given of a porphyritic biotite-gneiss of igneous origin and intrusive in the metamorphic schists and gneisses. Representatives of this rock appeared in every moraine from Hell's Gate to Priestley Glacier, and it was evident that the intrusion occupied a large area between Boomerang Glacier and Priestley Glacier.

A muscovite-bearing biotite-granite from the outer moraine of the Priestley Glacier appears to be different from the other granites already described. It varies considerably in grain and texture. In a porphyritic specimen (1821, 1693) there are buff-pink phenocrysts of orthoclase (2 cm. × 0·5 cm.) set in a light buff ground-mass of quartz, albite-oligoclase, and microcline, with biotite and muscovite. The biotite gives pleochroism $\beta = \gamma$ chestnut, α light buff. It contains numerous inclusions of zircon (?) surrounded by very dark and sharply-defined haloes.

The conspicuous pinkness of the felspars is no more a constant character here than it is in the case of the Granite Harbour type. In other specimens which do not show such marked porphyritic habit the pink colour is quite absent, and the resultant rock is a medium-grained white granite with crystals of microcline, up to 1 cm. in length, and many flakes of dark biotite, in a quartz-felspar ground-mass with a little muscovite (1613).

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* This report, No. 5 a, p. 150.

Some of the specimens of this granite contain thin cracks and veins filled with brick-red stilbite resembling in colour the well-known crystals from Old Kilpatrick Hills, Dumbartonshire.

Two finer-grained (2 mm.) white granites (1800, 1805) from the same moraine seem to belong to this type, and with it are associated some pale grey aplites and some specimens of white fine-grained pegmatitic veins carrying long slender prisms of tourmaline.

Very similar indeed to the muscovite-bearing granite just described are rocks collected at Cape Sastrugi (1677, 1681), some of which carry tourmaline and a little topaz (1664), and are in contact with coarse-grained tourmaline-pegmatites which are themselves intrusive in biotite-schists and gneisses.

The tourmaline-bearing pegmatites, which have just been noted in the Priestley Glacier moraine and at Cape Sastrugi, are, in fact, very widely spread, and occur in numbers along the Corner Glacier moraines. They are actually intrusive in the diorite in the bluff between Corner and Priestley Glaciers, and there are three specimens (1636, 1643, 1644) from the Boomerang-Campbell moraine on the east. In fact, the distribution of the Priestley Glacier type of granite and of the tourmaline-bearing pegmatites is exactly the same as that of the porphyritic biotite-gneiss described in No. 5 of this report, and I believe them to be actually connected with this intrusion, forming a partly tourmalinized zone in which muscovite and occasionally topaz are developed at the expense of the felspar.

Turning again to the dioritic rocks, we find these *in situ* on the bluff between Corner Glacier and Priestley Glacier (1361, 1362, 1363), where they include patches of biotite-schist. Several specimens were collected lower down the moraine of Corner Glacier and on the outer moraine of the Priestley Glacier. These differ somewhat from the dioritic rocks of the Northern Foothills in the hand-specimen. They are even-grained (2–4 mm.), black-and-white rocks, with biotite, felspar, and sometimes hornblende, all clearly recognizable. Under the microscope they are seen to consist of andesine ($Ab_3 An_2$) with rather subordinate quartz and about 30 per cent. of biotite and hornblende. Accessory constituents are not abundant, only very minute apatite crystals and some sphene being observed, and opaque iron ores are almost entirely absent. The sphene is usually enclosed in the biotite. The biotite in these rocks is in flakes 1–2 mm. across and gives pleochroism, chestnut to primrose-yellow. The hornblende gives pleochroism, γ bottle-green, β yellowish-olive, α reed-yellow, with $c : \gamma = 16°$. Several of the specimens exhibit contacts with biotite-schists, and with para-pyroxene-granulites,* and some show very evident traces of foliation.

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* This report, No. 5 b, p. 157.

It seems conceivable that the Northern Foothills and the block of land between Campbell Glacier and Priestley Glacier are occupied by parts of the same plutonic complex intrusive into the metamorphic rocks. If this is so, the dioritic rocks, the porphyritic biotite-gneiss, the muscovite-bearing granite of Priestley Glacier and Cape Sastrugi, and the tourmaline-bearing pegmatites and aplites may be successively younger members of one series of intrusions. All of these intrusions are later than the metamorphic rocks, and all seem to have been subjected to some foliation, best shown in parts of the porphyritic gneiss. It seems rather more difficult to admit into this series the granites and microgranites of Northern Foothills and Vegetation Island, which have not been recognized in any of the moraines to the west.

Still farther west the Beacon Sandstone formation makes its appearance, and erratics of it are found in the western moraine of the Priestley Glacier where they are associated with quartz-dolerite. With the quartz-dolerites are found erratics of fine-grained amygdaloidal "basalts" which differ from the Tertiary volcanics and seem rather to belong to the quartz-dolerites themselves.

CAPE ADARE AND ROBERTSON BAY.*

No plutonic or hypabyssal rocks have been found *in situ* at Cape Adare or on the coast of Robertson Bay, but considerable interest attaches to the foreign erratics which are found not only in the moraines of the Murray and Newnes Glaciers but also high up, over 800 feet above sea-level, at the northern end of Cape Adare (Fig. 12).

The only published descriptions of any erratics from the neighbourhood are based on the collections made by C. E. Borchgrevink, both in 1894 on the "Antarctic" and again in 1899 on the "Southern Cross" Expedition, when he wintered at Cape Adare. The specimens collected in 1899 were described by Dr. G. T. Prior.† The earlier expedition of 1894 had yielded only one example of the eruptive rocks, a garnetiferous aplite,‡ quite similar to erratics from Possession Island described by Prior and collected, one by Borchgrevink, and another earlier by the Ross Expedition of 1839. §

ERRATICS HIGH UP ON CAPE ADARE.

Priestley's collection of the foreign erratics on Cape Adare includes many representatives of the slate-greywacke formation, but numerous granites and associated dike rocks are also present, and a fair number of boulders of quartz-dolerite exactly similar to the dolerites intrusive in the Beacon Sandstone in the McMurdo Sound region. The granites and associated dike rocks are for the most part similar to those already recorded by Prior, but some of them are new and, as many of the erratics show interesting resemblances to rocks now known to occur in the Terra Nova Bay region, a brief account of their characters will not be out of place.

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* Descriptions are based on the collection made by Mr. R. E. Priestley in 1911.

† Prior (G. T.), *loc. cit.*, pp. 322-325.

‡ David (T. W. E.), Smeeth (W. F.), and Schofield (J. A.), Journ. & Proc. Roy. Soc. N.S.W., 1895, vol. 29, p. 471.

§ Prior (G. T.), Min. Mag., 1899, vol. 12, p. 79.

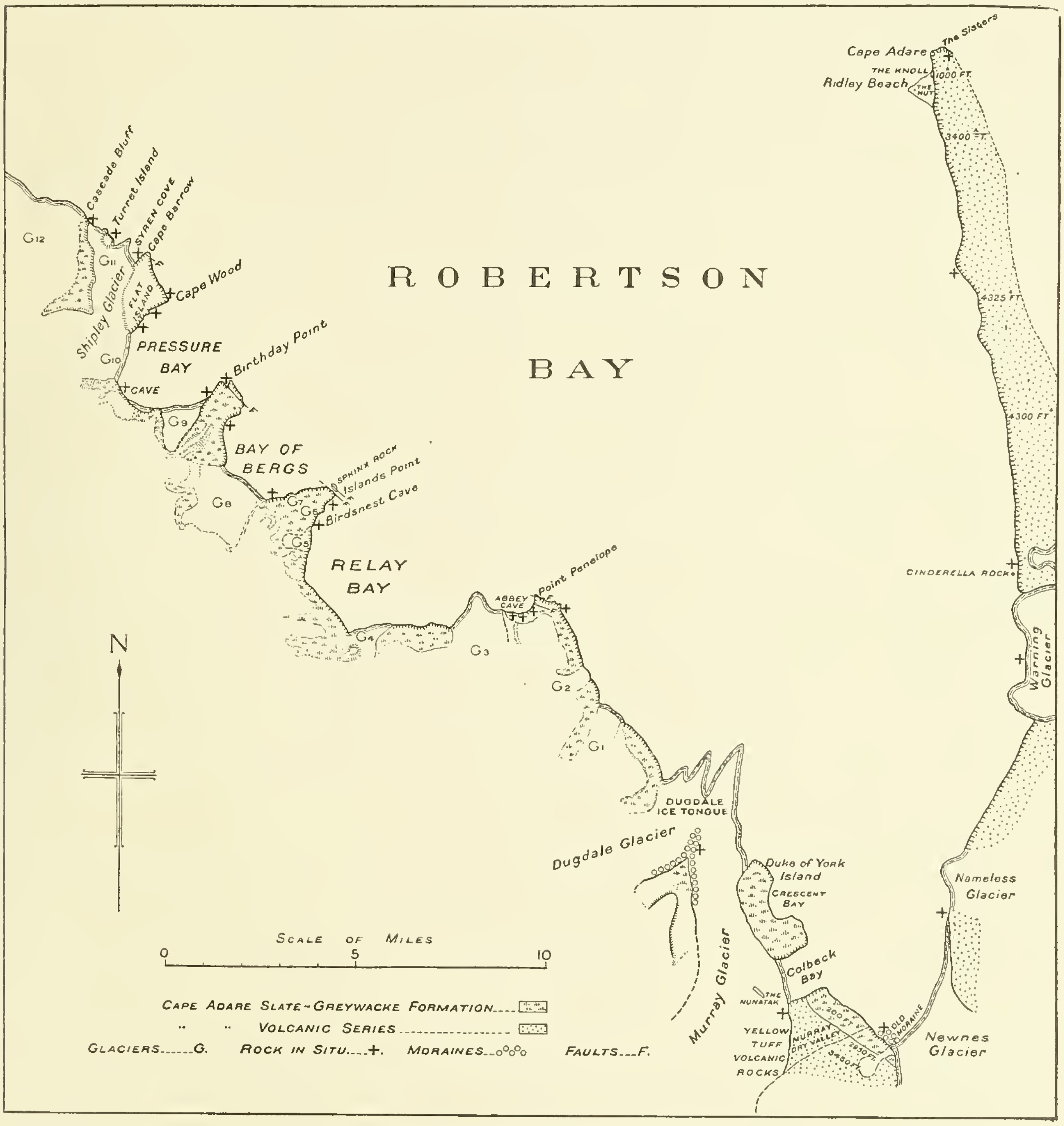

FIG. 12.—Map of Robertson Bay region.

Reference has been made in a previous part of this report to the fact that a boulder identical in character with the porphyritic biotite-gneiss of the Terra Nova

Bay region had been found by Borchgrevink in 1899 at Cape Adare. Another erratic of the same kind was collected by the present expedition. The two boulders have been compared with numerous specimens from the Terra Nova Bay region, and there can be no doubt that the resemblances are very close indeed.

This is by no means an isolated example of the presence among the erratics on the top of Cape Adare of types known to occur further south.

A hornblendic biotite-microcline-granite collected by Borchgrevink, but not described by Prior, is identical with a cream-coloured granite (1966, 1969) found as erratics in Hell's Gate moraine, Terra Nova Bay. Two or three specimens (287, 566) closely resemble the non-porphyritic habit of the grey granite (Granite Harbour type) which is known to occur at Terra Nova Bay as well as at Granite Harbour, and another (366) is absolutely indistinguishable in the hand-specimen from one of the red veins (D57G) found in the grey granite at Cape Geology, Granite Harbour.

Among the dike rocks from Cape Adare, Prior has already recorded a red porphyritic granophyre (*loc. cit.*, p. 324) and hälleflinta-like felsites (*loc. cit.*, p. 325), and both these types have been found again by Priestley. The "red porphyritic granophyre" is very similar to the red quartz-orthoclase-porphyry (D12G) of Granite Harbour, and a pebble (474) from Priestley's collection is indistinguishable from some specimens from dikes on The Flatiron. Hälleflinta-like felsites, quite similar to those described by Prior, were found by Priestley as erratics on the island next to Depot Island (p. 191).

The other specimens collected by Priestley have not been definitely recognized as types known farther south.

A pale pink microgranite (1229) intrusive in a hornblende-biotite-gneiss compares well in outward appearance with the microgranite of Hell's Gate moraine, but it contains no microcline and but little plagioclase, the bulk of its felspar being orthoclase or microperthite.

Other granites include several specimens of the biotite-granite with pink porphyritic felspars described by Prior, another pink granite with numerous pink crystals of orthoclase, and a grey granite with abundant muscovite in addition to biotite rather resembling some of the erratics collected on the outer moraine of the Priestley Glacier.

Among dike rocks there are a pink aplite and one or two grey quartz-orthoclase-porphyries with no very distinctive characters, and three porphyries with a fine-grained granulitic ground-mass which possibly belong to an earlier group of intrusions.

Quartz-dolerites, quite similar to the intrusive sills in the Beacon Sandstone, occur among the erratics and are represented in the collection by about eight specimens.

It seems quite evident that many of the erratics left high up on Cape Adare have been derived from an area in which many of the Terra Nova Bay and Granite Harbour rock-types are repeated. Mr. Priestley considers that although evidence apart from the composition of the moraines, points to a southern source for the ice which planed down the north end of Cape Adare, yet it is improbable that this source of origin was as far south as Terra Nova Bay itself. In his memoir on the Physiography of the Robertson Bay region (p. 10), when writing of these moraines on Cape Adare, he says: "To account satisfactorily for the occurrence of these moraines one must visualize the onward movement of a magnificent sheet of ice filling the Bay from back to front and at least a thousand feet thick. Such a sheet must have had its origin from some ancestors of the glaciers at present filling the valleys at the head of the Bay. It is difficult to conceive it as the output of a local Highland-ice sheet. It is more reasonable to suppose that we are here dealing with the remains of the extension of some great Continental-ice which formerly shouldered its way past Mount Sabine and found its overflow down the coastal valleys."

Mr. Priestley regards the probable direction of movement as from rather west of south, and he has suggested the Mount Sabine area as a possible source of the granitic rocks.

The resemblance of no less than six different types of erratics to Terra Nova Bay or Granite Harbour rocks is so striking that one hesitates to discard as impossible the idea that the Terra Nova Bay region may be the source of the boulders, but between Mount Melbourne and Robertson Bay lie 200 miles of unknown country, and Mr. Priestley's view is that somewhere in this area, possibly in the Admiralty Range, we have a repetition of the granitic rocks of the type with which we were first made familiar in the Ferrar Glacier region and which have since been found to recur both at Granite Harbour and again at Terra Nova Bay.

ERRATICS FROM THE MURRAY GLACIER.

The only other sources from which erratics of eruptive rocks were collected in the vicinity of Cape Adare were the moraines of the Murray Glacier. Here were found no true granites but numerous specimens of dioritic rocks ranging in composition from rocks so rich in quartz as to be classed as granodiorites to basic diorites, similar to the rocks now classed as olivine-diorites by Harker.

Most of these rocks were collected from the south side of Colbeck Bay; two of the more acid type came from the Murray "Dry Valley."

The more acid rocks of this series contain abundant quartz and some orthoclase as well as plagioclase (oligoclase-andesine), biotite, and hornblende. The hornblende was originally brown with pleochroism, α cream-buff, $\beta = \gamma$ tawny-olive; $c : \gamma = 17\frac{1}{2}°$. The biotite is intensely pleochroic, $\beta = \gamma$ blackish-brown, α warm-buff to cream-buff. The accessory constituents are a black iron oxide, apatite, and sphene. The iron oxide and sphene are enclosed by the biotite. Much alteration has gone on, the felspars being very much saussuritized, biotite altering to chlorite, and strongly pleochroic epidote developing rather abundantly, often within the biotite.

In another variety with less quartz and no orthoclase, the biotite and its alteration products are more abundant, and the felspar, which is basic andesine, is strongly zoned. The mode of alteration is similar to that of the more acid rock. This is a *quartz-biotite-diorite.*

The other rocks are much more basic blackish-grey rocks which, under a lens, are seen to consist of idiomorphic black hornblendes with a little pinkish felspar evenly distributed in the interstices. In its original condition the rock appears to have been an *olivine-bearing diorite* similar to some of the rocks described by Allport from Marston Jabet in Warwickshire,* or to the basic diorite of Inchnadampf, Sutherlandshire, described by Sir J. J. H. Teall.†

These rocks consisted of hornblende, biotite, and plagioclase, with olivine, but they have been very much altered and a certain amount of free quartz has made its appearance. The hornblende, perhaps originally brown, is now mostly green; $c:\gamma = 16\frac{1}{2}°$; α very pale yellow, β cress-green, γ grape-green to dark olive-buff.

All the biotite is altered to chlorite, and there are numerous patches of calcite dusted with magnetite, which represent pseudomorphs of olivine and are very similar to those described by Allport in the diorite of Purley Park, Atherstone.‡ The hornblendes vary in size from 1–2 mm. down to quite small crystals, most of the small ones being of later growth. The olivine is so abundant in one specimen (1124) that this must approach in composition the rocks classed as olivine-diorites by Harker and described by several writers as picrite. The alteration is of the same type as has been described above, with saussuritization of felspar and the development of much epidote.

These rocks are in some respects similar to the diorites of the Northern Foothills, but there is not here that same clear and convincing similarity which exists between the granite erratics of Cape Adare and the granitic rocks of the Terra Nova Bay region and of Granite Harbour.

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* Allport (S.), Quart. Journ. Geol. Soc., 1879, vol. 35, p. 638.

† Teall (J. J. H.), Geol. Mag., 1886, dec. 3, vol. 3, pp. 346–351.

‡ Allport (S.), *loc. cit.*, p. 640.

THE BEARDMORE GLACIER.

"*Friday, March 16 or Saturday 17—Yesterday we had to lay up for a blizzard and to-day we move dreadfully slowly. We are at No. 14 pony camp, only two pony marches from One Ton Depôt. We leave here our theodolite, a camera, and Oates' sleeping-bags. Diaries, &c., and geological specimens carried at Wilson's special request, will be found with us or on our sledge.*"—The Journals of Captain R. F. Scott, R.N., C.V.O.*

"*We recovered all their gear and dug out the sledge with their belongings on it. Amongst these were 35 lb. of very important geological specimens which had been collected on the moraines of the Beardmore Glacier; at Doctor Wilson's request they had stuck to these up to the very end, even when disaster stared them in the face and they knew that the specimens were so much weight added to what they had to pull.*"—The Last Year at Cape Evans with the finding of the Polar Party. By Surgeon E. L. Atkinson, R.N.†

The specimens referred to in the two passages just quoted are those collected by Captain Scott's Polar party on their journey back from the South Pole in January and February, 1912.

No one who has the privilege of examining these specimens and who knows the details of the tragic journey on which they were collected can fail to feel that here are specimens of inestimable value to be treasured in the national collections and to be examined with care and patience, so that, if possible, every stone may play its part in the piecing together of the geological history of the Beardmore Glacier.

More than half the bulk of this collection consisted of sedimentary rocks with samples of coal and fossil plants. The Beacon Sandstone specimens have been described briefly by Mr. Debenham, who has given some account of the Beardmore Glacier, illustrating his description by one of Dr. Wilson's remarkably good geological sketches and an admirable photograph taken by Mr. C. S. Wright.‡ Undoubtedly the most important among all the specimens are the fossil plants collected by Dr. Wilson near Mount Buckley and fully described by Prof. A. C. Seward in the first part of this report.§ The samples of coal are similar to those collected by the Shackleton Expedition of 1907–9 which have been dealt with by Prof. Sir Edgeworth David in the Geological Report of that expedition.||

Besides these sediments of the Beacon Sandstone formation the collection includes specimens of the limestone with *Archaeocyathus*, previously discovered *in situ* by Sir Ernest Shackleton, and a few fragments of metamorphosed sediments of which no account has as yet been published. A description of these pre-Beacon Sandstone sedimentary rocks will form the subject of a later part of this report.

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* Scott's Last Expedition, Vol. 1 (1913), p. 593.

† *Ibid.*, Vol. 2 (1913), p. 346.

‡ This report, No. 4 (1921), pp. 113–19, Figs. 6, 7.

§ This report, No. 1 (1914), pp. 5–9.

|| David (T. W. E.) and Priestley (R. E.), Brit. Ant. Exp., 1907–9, Geology, Vol. 1 (1914), p. 250.

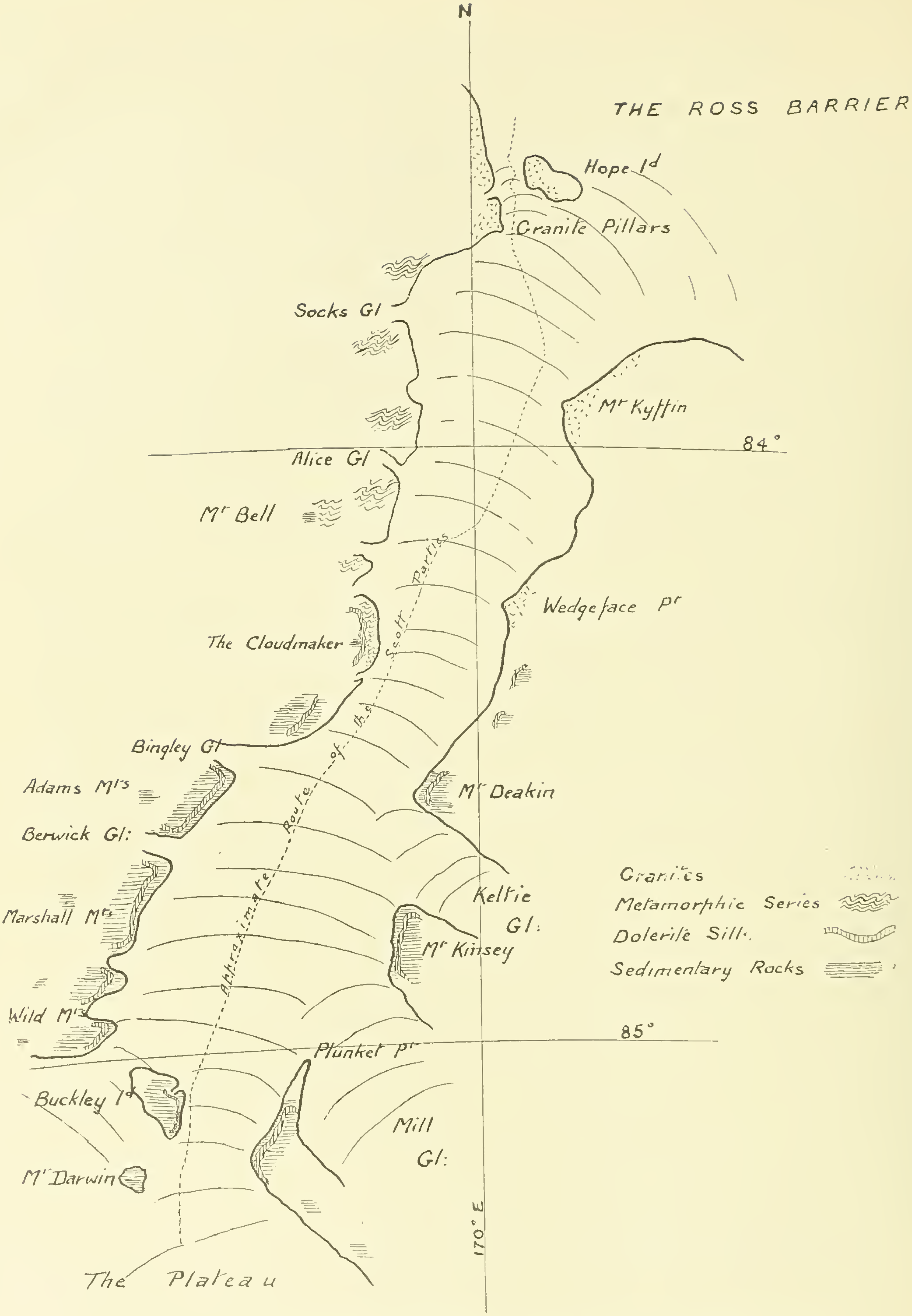

Fig. 13.—Sketch-map of the Beardmore Glacier. (Scale approximately 10 miles to the inch.)

Quartz-dolerites.

The observations of Sir Ernest Shackleton and his Polar party on their journey up the Beardmore Glacier in 1908 made it quite clear that between The Cloudmaker and Mount Buckley the mountains on the western side of the glacier are formed of Beacon Sandstone, intruded by horizontal sills of dolerite exactly similar to those already recorded in other parts of South Victoria Land. These observations were abundantly confirmed by Captain Scott's party, and both in the photographs and in Dr. Wilson's annotated geological sketches many details of the nature of the dolerite sills are shown.

It seems possible that the Beacon Sandstone formation may actually extend to the mountains east of the glacier. Looking at these mountains from about the middle of the glacier on December 12th, Capt. Scott wrote : * "There are interesting features showing up—a distinct, banded structure on Mount Elizabeth, which we think may well be a recurrence of the Beacon Sandstone—more banding on the Commonwealth Range." And again, four days later,† "The hills on our left have horizontally stratified rock alternating with snow. The exposed rock is very black ; the brownish colour of The Cloudmaker has black horizontal streaks across it."

This last note and the presence of sandstone and dolerite in the moraines under The Cloudmaker make it highly probable that the Beacon Sandstone and the dolerites occur at any rate in the upper part of this mountain.

The South Polar party collected altogether twenty-five specimens of the quartz-dolerites from the moraines near The Cloudmaker, from Mount Buckley, and from Mount Darwin. The specimens collected by Lieutenant Bowers at Mount Darwin are of the very greatest importance, as they settle one much-debated point as to the structure of this particular part of the Beardmore Glacier.

Among the specimens collected by the Shackleton Expedition some of the most important were the massive limestones with irregular green streaks collected *in situ* at the farthest south exposure of rock which Shackleton's party touched, apparently Mount Buckley. The limestone contains traces of *Archaeocyathus,* which proves it to be of Cambrian age, and it has been thought to be the source from which a limestone-breccia found in moraines near The Cloudmaker was derived.

There has been some difference of opinion as to the exact relations of this limestone at Mount Buckley to the Beacon Sandstone, but Prof. Sir Edgeworth David and Mr. Priestley were led to the conclusion that the whole of Mount Darwin, five or six miles south-west of Mount Buckley, is of Cambrian limestone and is the source of a limestone-breccia at Mount Buckley, and they showed it as such in their section of the Beardmore Glacier, although the difficulty of explaining its position there was considerable.*

---

* Scott's Last Expedition, Vol. 1 (1913), p. 500.

† *Ibid.*, p. 506.

Captain Scott evidently had it in mind to solve this problem of the nature of the pink-weathering rock of Mount Darwin, which was believed to be limestone. In his journal he writes :†

"Feb. 8.—. . . . Steered in for Mount Darwin to visit rock. Sent Bowers over, on ski, as Wilson can't wear his at present. He obtained several specimens, all of much the same type, a close-grained granite rock which weathers red. Hence the pink limestone."

Later in the day Dr. Wilson "got a specimen of limestone with archaeocyathus" on the moraine under Mount Buckley.

The specimens collected at Mount Darwin by Bowers (P48 and P50) prove to be not a granite but a quite typical quartz-dolerite of the McMurdo type. The larger specimen (P50) is medium-grained, the other (P48) very fine-grained. Both are stained red on the weathered surface. This discovery makes it absolutely certain that the dolerite sills of the Beacon Sandstone formation extend south-west from Mount Buckley to Mount Darwin. It is highly probable that dolerite forms the whole of the pink capping of Mount Darwin, and its position there is quite normal. The problem of the true position of the Cambrian limestone of the Mount Buckley moraine remains, and will be discussed in another part of the report.

There is something remarkably impressive in the persistence of these quartz-dolerite sills which this expedition has shown constitute the most southern outcrop of rock in the known world. Mr. Debenham in his preliminary notes on "The Geological History of South Victoria Land" has alluded to the great dolerite intrusions as the McMurdo Sill.‡ He gave its north-to-south extent as from latitude 71° S. to 85° S., and estimated its area as probably exceeding that of Great Britain and Ireland. Since he wrote, Sir Douglas Mawson has discovered still further intrusions of the same dolerites in King George Land, on the Antarctic Circle, somewhat over 1,300 miles from their most southerly outcrop at Mount Darwin.

In the collection which Dr. Wilson made at Mount Buckley there are eight specimens of quartz-dolerites. Some of these are quite typical and show the characters so fully described by W. N. Benson and W. R. Browne, but three of them are exceedingly fine-grained and one (P4) shows small round vesicles filled with zeolites. These very fine-grained rocks have been referred to as lavas, and it has been suggested that lavas equivalent to the volcanics of McMurdo Sound might be found here. This, however, is not the case. In mineral composition they appear to be identical with the quartz-dolerites. Specimen P9 consists of numerous thin plagioclase laths and grains of augite in a glassy base; the others appear to be exceedingly fine-grained dolerites. Similar fine-grained types are found in the moraines of The Cloudmaker and can be compared with the marginal varieties of the quartz dolerites described and figured by G. T. Prior.* Reference has been made to similar fine-grained and vesicular dolerites in the material from the Priestley Glacier (p. 214). It appears highly probable that these so-called lavas are really marginal modifications of the quartz-dolerite. If they are true lavas they must be very intimately associated with the intrusion of the quartz-dolerites, and they were probably contemporaneous with the sills.

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* David (T. W. E.) and Priestley (R. E.), Brit. Ant. Exp., 1907–9, Geology, Vol. 1 (1914), p. 241.

† Scott's Last Expedition, Vol. 1 (1913), p. 563.

‡ *Ibid.*, Vol. 2 (1913), p. 436.

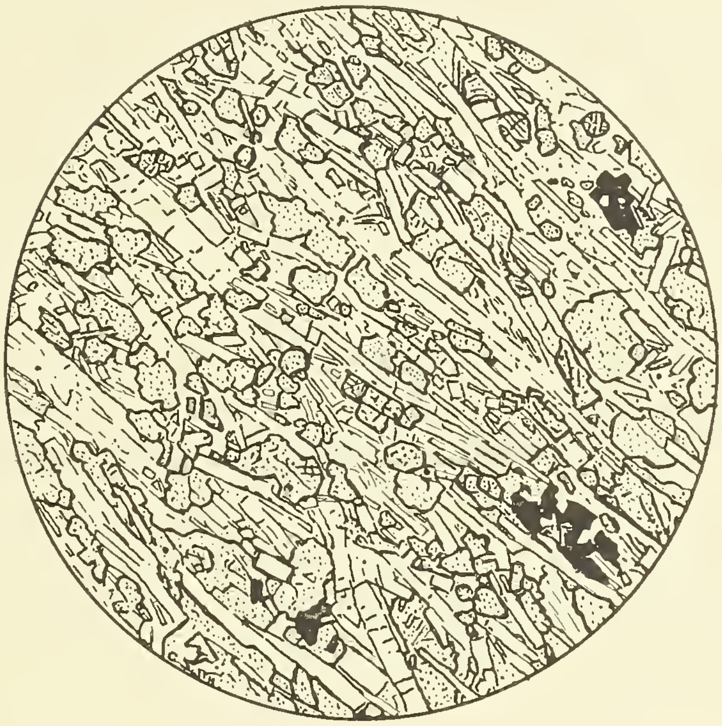

Fig. 14.—Quartz-dolerite (P107), from moraine near The Cloudmaker. Showing parallel-intergranular texture. Magnification 42 diameters.

The dozen specimens brought back from the moraines near The Cloudmaker show most of the characters described by W. N. Benson. Many of them are very fine-grained varieties. One is very similar to the rock from within two feet of the sandstone at Dry Valleys, Ferrar Glacier region, figured by G. T. Prior.† Others (P59, P93) show rather rare crystals of rhombic pyroxene or pseudomorphs after this mineral like those described by Benson. Another specimen (P107) shows a remarkably well-defined parallel texture in which the pyroxene all occurs as grains, of which many are elongated, conforming to the general parallelism of the laths of labradorite. This unusual texture may be described as *parallel-intergranular* (Fig. 14). Most of the other specimens are quite typical of the quartz-dolerites of McMurdo Sound.

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* Prior (G. T.), Nat. Ant. Exp., 1901-4, Natural History, Vol. 1 (1907), p. 138.

† *Ibid.*, Pl. X, Fig. 2.

Granites.

Mount Hope.

Shackleton in 1908 had recorded a large mass of granite forming Mount Hope and Granite Pillars at the entrance to the Beardmore Glacier, but it was not until 1916 that a description of the rock based on two specimens collected at Shackleton's Lower Glacier Depot was published by Sir Douglas Mawson.* In the meantime J. Schetelig † had, in 1915, given detailed descriptions, figures, and analyses of granites collected by Roald Amundsen (1911–12) at Mount Betty on the Axel Heilberg Glacier, about 200 miles east of Mount Hope, and at Scott's Nunataks in King Edward VII Land. At both these places he recorded a true granite consisting of orthoclase and microcline, oligoclase, quartz, biotite, and muscovite, with apatite, magnetite, and zircon.

From an analysis of the granite at Scott's Nunataks he calculated the following mineral composition :—

Quartz 21·1, perthitic orthoclase 52·3, plagioclase 20·7, mica, &c. 5·9.

Mawson's description of the two specimens from near Mount Hope shows that the Mount Hope granite closely resembles the granite of Scott's Nunataks. It contains both muscovite and biotite, and is rich in microcline. One of his specimens showed a porphyritic texture. Measurements on the second specimen, a fine-grained granite, showed the approximate mineral composition to be as follows :—

Quartz 26, orthoclase and microcline (and anorthoclase) 51, plagioclase 19, mica 4.

The specimens collected by Scott's Expedition in the neighbourhood of Mount Hope correspond well with the description given by Mawson of his porphyritic variety. The South Polar party collected also one or two chips of pegmatite with smoky quartz in graphic intergrowth with felspar. Captain Scott's journal records a large boulder of coarse granite lying on the glacier about three miles beyond his Lower Glacier Depot and near Granite Pillars.

The specimens of the granite do not afford sufficient material for analysis, and direct comparisons have not been possible, but the published descriptions of the rocks and the estimates of mineral composition given above make it clear that the granites of Mount Betty and of Scott's Nunataks are very similar to the granite of Mount Hope.

Schetelig has suggested that the granites from Mount Betty are connected with the intrusive granites farther north in South Victoria Land. He had seen at the

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* Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, Vol. 2 (1916), p. 213.

† Schetelig (J.), Report on Rock-specimens collected on Roald Amundsen's South Pole Expedition. Videnskaps. Skrifter Christiania, I, Mat.-naturv. Klasse, 1915, No. 4, 32 pp.

British Museum specimens of the grey granite of Granite Harbour collected by the "Discovery" Expedition and found them "very similar to the light-coloured granite samples from Mount Betty". Comparison of the granite of Mount Hope with the biotite-granite of Granite Harbour does not, however, show any close similarity. As we now know, the Granite Harbour type is characterized by a high content of plagioclase, rather abundant biotite, little orthoclase, and rather low silica : on the other hand the granites of Mount Hope, Mount Betty, and Scott's Nunataks contain

TABLE VI.

	1. Aplitic granite. Mount Betty.	2. Plagioclase-granite. Mount Betty.	3. Granite. Scott's Nunataks.	4. Hornblendic biotite-granite. Cape Irizar.	5. Biotite-granite. Northern Foothills.	6. Biotite-granite. Mount Larsen.	7. Biotite-granite. Granite Harbour.
SiO_2	73·10	74·65	73·00	71·87	71·55	69·85	68·33
Al_2O_3	15·14	14·41	13·01	15·16	13·41	15·35	16·56
Fe_2O_3	0·06	0·52	0·13	0·62	1·60	0·40	0·34
FeO	0·16	1·08	1·08	2·10	1·26	3·88	2·82
MnO	tr.	0·02	0·01	0·04	tr.	0·06	tr.
MgO	0·15	0·50	0·62	0·29	0·64	0·52	0·61
CaO	1·18	2·63	0·63	0·84	2·46	2·94	3·43
Na_2O	3·96	4·36	4·04	3·88	3·46	3·13	3·85
K_2O	6·13	1·18	7·00	4·72	4·84	2·87	3·56
H_2O+	0·32	0·60	0·31	0·35	0·15	0·24	0·38
H_2O-	0·11	0·12	0·10	0·15	0·40	0·03	0·04
TiO_2	tr.	0·22	0·20	0·25	0·21	0·36	0·29
P_2O_5	0·05	0·06	0·31	tr.	0·08	0·50	0·23
S	0·10	0·08	0·08	—	—	—	—
CO_2	—	—	—	0·09	—	0·01	—
	100·46	100·43	100·52	100·36	100·06	100·14	100·44

1, 2, 3. Schetelig (J.), Videnskaps. Skrifter Christiania, I, Mat.-naturv. Klasse, 1915, No. 4.
4, 6. Mawson (D.), Brit. Ant. Exp., 1907–9, Geology, Vol. 2 (1916).
5, 7. This report, No. 6, Terra Nova Bay region and McMurdo Sound.

muscovite as well as biotite and a high content of potash-felspar. The differences between the two groups of granites are shown conclusively by the analyses given in Table VI. Even in the plagioclase-granite of Mount Betty, described by Schetelig, there is no close approach to the composition of the biotite-granite either of Granite Harbour or of Mount Larsen.

The only area in South Victoria Land, except Mount Hope, in which granites rich in potash-felspar have been recorded hitherto is the Terra Nova Bay region where some erratics from the Priestley Glacier moraines do contain muscovite as well as biotite, so that there is a possibility that granites similar to those of Mount Hope and Mount Betty do occur in this area. It has been shown above that these microcline-bearing granites of the Terra Nova Bay region are probably quite distinct from the granites of the Granite Harbour type, and there is at present no evidence as to their age. Schetelig has, however, shown that the granite of Mount Betty is younger than the gneisses and amphibolites of that area, and the same is probably true of the Mount Hope granite. This in itself is a valuable addition to our knowledge.

The Moraines near The Cloudmaker.

Two small fragments of a biotite-granite were found in the moraines near The Cloudmaker. The discovery of granite as far south as this point, latitude 84° S., is quite new, and the specimens are of very great interest for they do seem to show a resemblance to the pre-Beacon Sandstone granites of Granite Harbour and they are quite different from the granite of Mount Hope. Both the specimens are very much weathered, and in one (P117) the biotite and the felspars are completely altered.

The fresher specimen (P115) is a fine-grained pale grey granite consisting of half-millimetre flakes of brown biotite, laths of oligoclase (Ab_4 An_1), orthoclase, and quartz, with apatite, magnetite (or ilmenite), and zircon as accessory constituents. The grain is very even, 0·5 mm., and the texture is panidiomorphic-granular (Rosenbusch), and indicates that the rock probably forms part of a small intrusion. Quartz is not abundant and occurs mainly in graphic intergrowth with the orthoclase; only 15 per cent. could be measured in the section but more is probably present in the fine-grained patches of micropegmatite. The oligoclase forms lath-shaped crystals half a millimetre across and one to two millimetres long and is probably slightly more plentiful than the orthoclase.

The appearance of this granite and its richness in both plagioclase and biotite at once recalled the characters of the grey biotite-granite of Granite Harbour. Compared with sections of the Granite Harbour type from Granite Harbour and from the Terra Nova Bay region, the texture of the fragment from The Cloudmaker moraine is more nearly panidiomorphic and it shows no traces of pressure effects, but the mineral composition is very similar. Attempts to measure the relative proportions of minerals present failed to give reliable results on account of the state of alteration of the felspars in the granite from The Cloudmaker, and only the ratio of biotite to colourless constituents was determined. The percentage of biotite present in the series of sections measured is as follows :—

	No.	%
Granite Harbour type, Granite Harbour	D9G	15·0
	D38G	11·5
Ferrar's No.	155	11·0
,, ,, ,, Terra Nova Bay	1426	13·5
(melanocratic variety)	1472	26·5
	1473	10·0
Calculated from analysis of Mount Larsen granite		23·0
Granite from moraine off The Cloudmaker	(P115)	19·0
,, (a much-altered specimen)	(P117)	8·0

These figures serve to show that the biotite-content in The Cloudmaker granite is of the same order as in the biotite-granite of Granite Harbour and Mount Larsen, and is much higher than in the granites of Mount Betty or Mount Hope, or in the microgranite of the Northern Foothills type, in which measurements show the biotite-content to be about 4·5 per cent.

It seems probable that the little fragment from The Cloudmaker moraine is a representative of the Granite Harbour type, which may outcrop from beneath the Beacon Sandstone somewhere near The Cloudmaker, and the connexion suggested by Schetelig with South Victoria Land may exist here though not at Mount Betty. If this is so, it forms another instance of the rather remarkable continued reappearance of this type of granite at nearly every point where explorers have penetrated inland from the coast of South Victoria Land.

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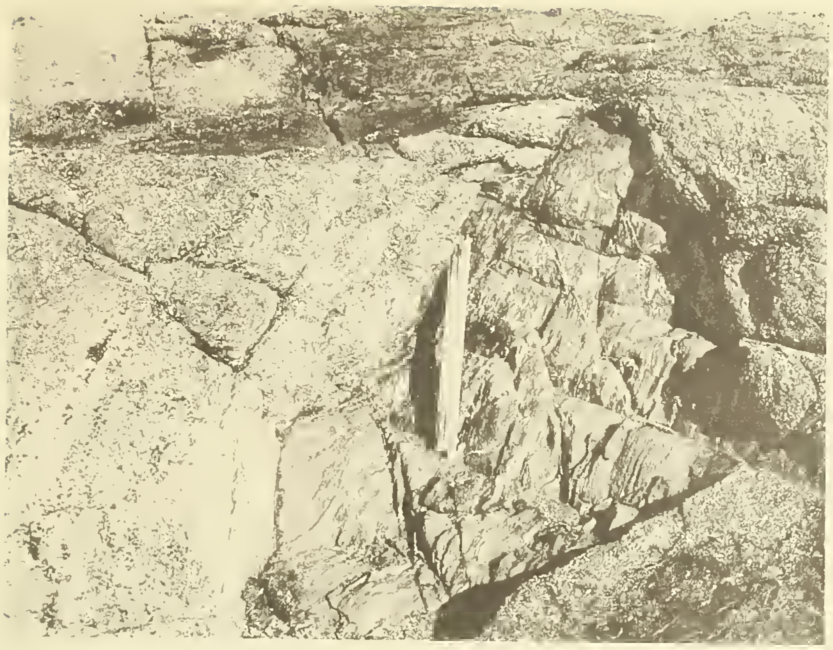
PLATE I.

Fig. 1. Gneiss included in grey granite. Cape Geology, Granite Harbour. (p. 176.)
Fig. 2. Orbicular hornblendic patches in grey granite. Boulder on Cape Geology. (p. 176.)
Fig. 3. Hornblendic patches in grey granite. Cape Geology. (p. 169.)
Fig. 4. Porphyritic grey biotite-granite (Granite Harbour type). Cape Geology. (p. 178.)
Fig. 5. Acid veins penetrating limestone. Marble Dike, The Flatiron, Granite Harbour. (pp. 181, 182.)
Fig. 6. Marble Dike, as seen from the sea-ice. (pp. 176, 181.)



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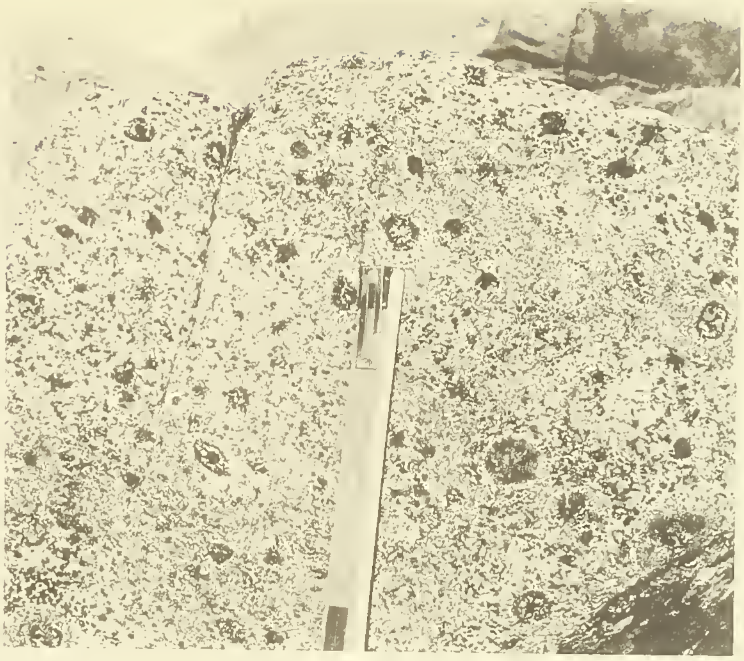

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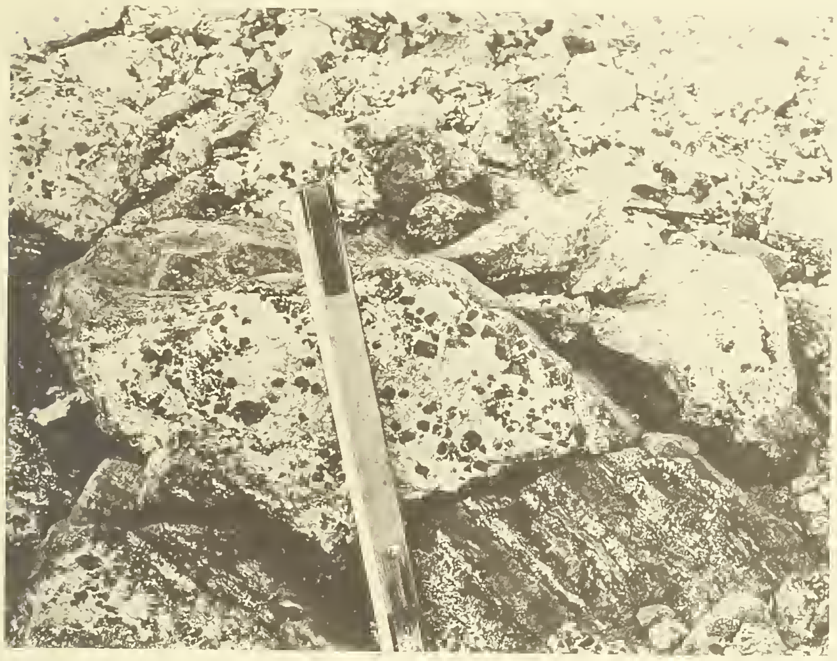

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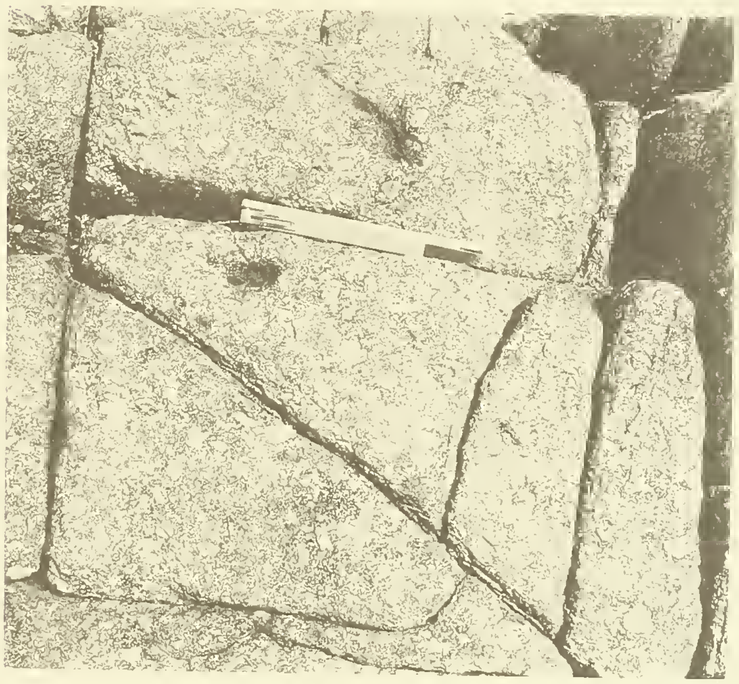

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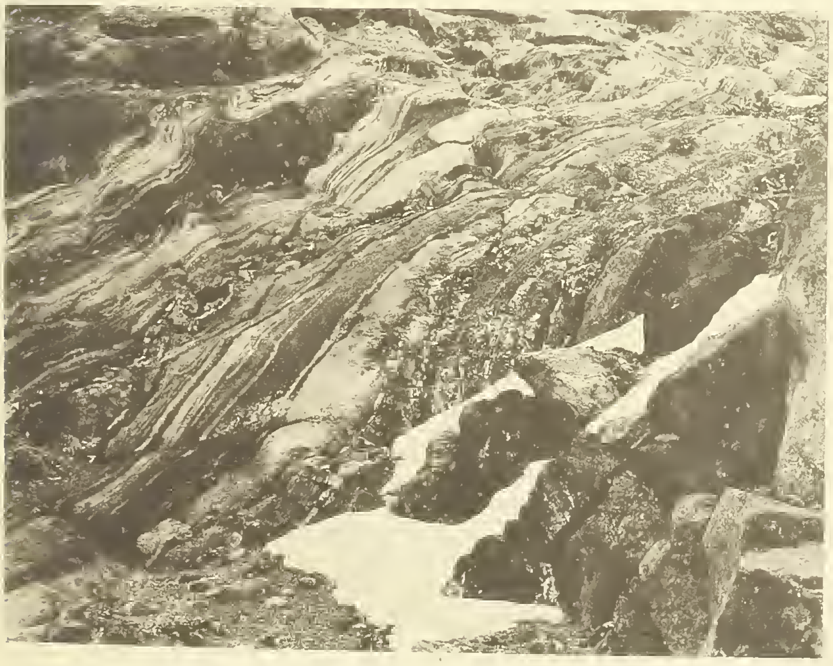

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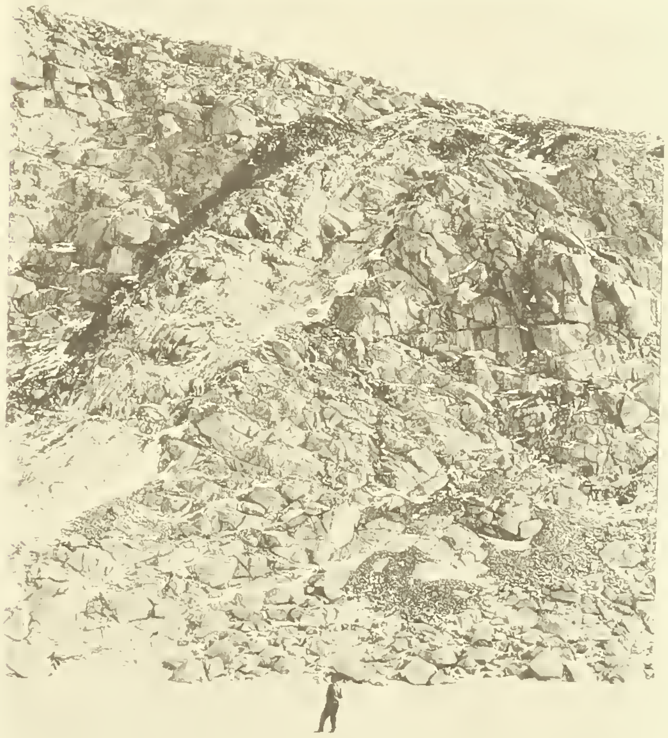

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F. Debenham, photo.

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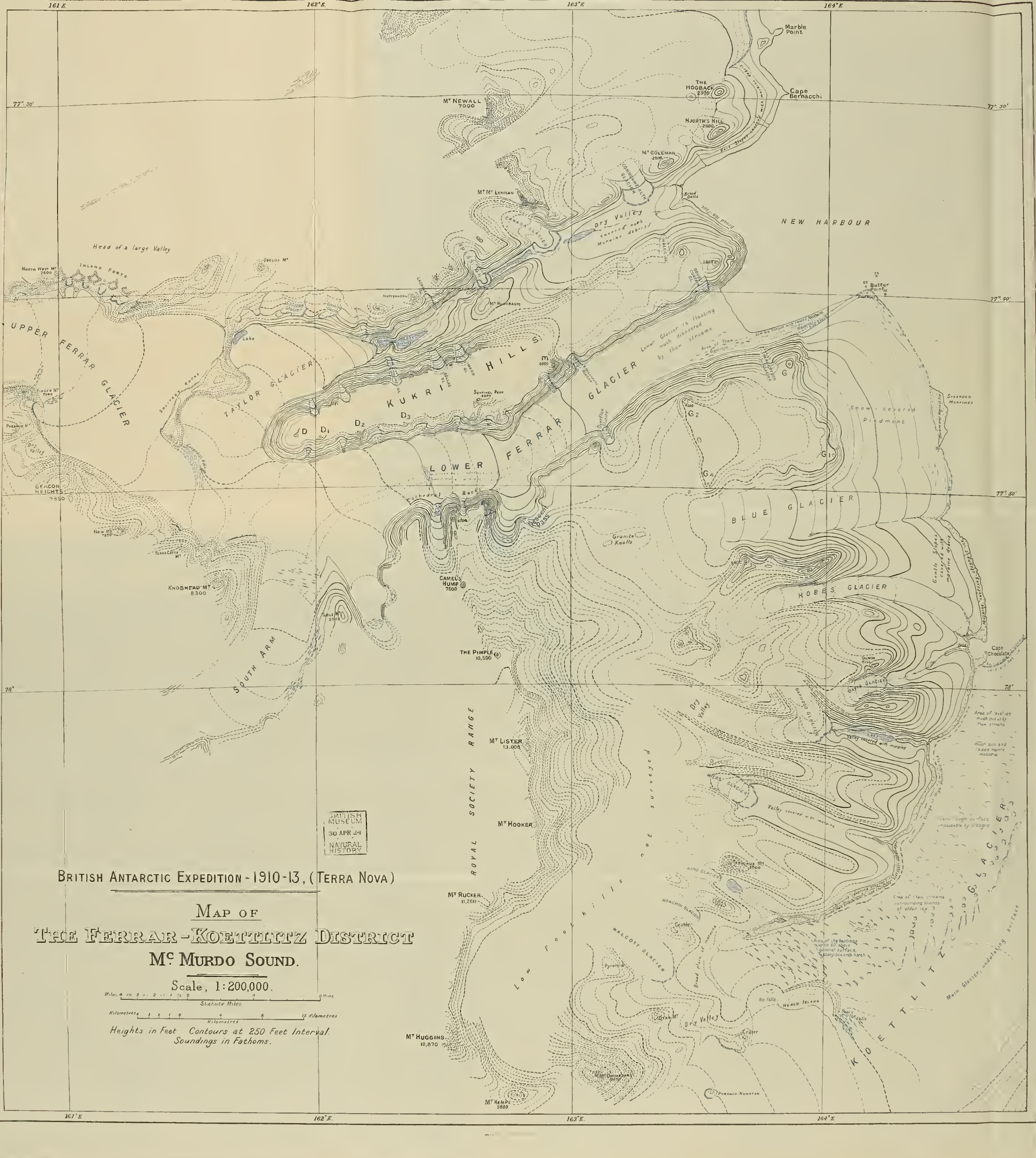

British Antarctic Expedition - 1910-13, (Terra Nova)

Map of
The Ferrar-Koettlitz District
Mc Murdo Sound.

Scale, 1 : 200,000.

Miles 4 3 2 1 0 4 8 Miles
Statute Miles.
Kilometres 4 3 2 1 0 4 8 12 Kilometres
Kilometres

Heights in Feet. Contours at 250 Feet Interval.
Soundings in Fathoms.

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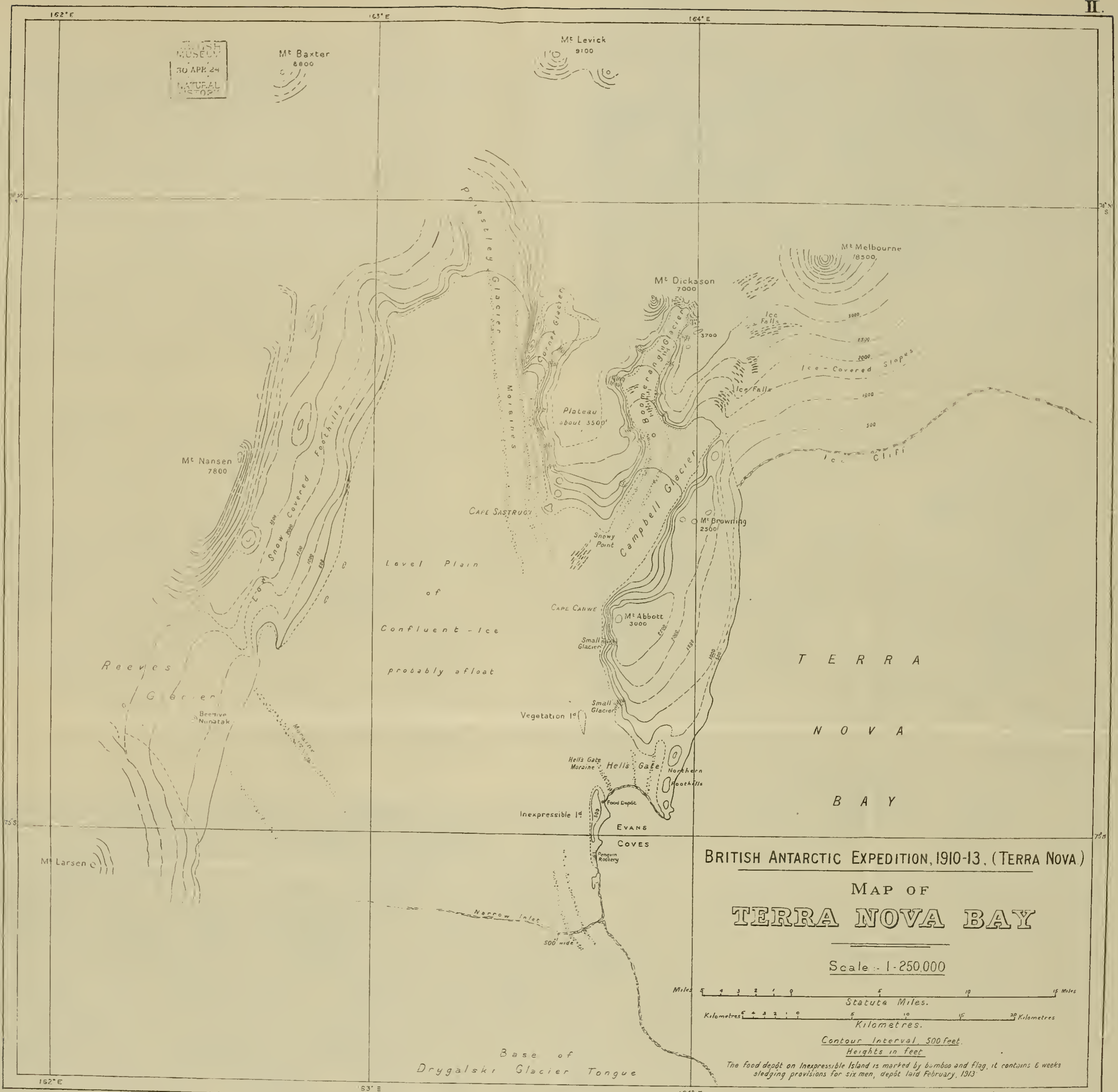

BRITISH ANTARCTIC EXPEDITION, 1910-13. (TERRA NOVA.)

MAP OF

TERRA NOVA BAY

Scale :- 1-250,000

Miles 5 4 3 2 1 0 5 10 15 Miles
Statute Miles.
Kilometres 5 4 3 2 1 0 5 10 15 20 Kilometres
Kilometres.

Contour Interval, 500 feet.

Heights in feet

The food depôt on Inexpressible Island is marked by bamboo and flag, it contains 6 weeks sledging provisions for six men, depôt laid February, 1913.

PRESENTED
4 JAN 1955

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BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910

NATURAL HISTORY REPORT

GEOLOGY. VOL. II. No. 1. Pp. 1—107.

THE VOLCANIC ROCKS OF THE ROSS ARCHIPELAGO

BY
W. CAMPBELL SMITH

WITH EIGHT FIGURES IN THE TEXT, SIX PLATES, AND TWO MAPS

LONDON:
PRINTED BY ORDER OF THE TRUSTEES OF THE BRITISH MUSEUM
Sold by B. Quaritch, Ltd., 11 Grafton Street, New Bond Street, W.1;
H.M. Stationery Office, York House, Kingsway, W.C.2
and at the
British Museum (Natural History), Cromwell Road, London, S.W.7
1954

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Price Three Pounds

[*Issued 25 November 1954*]

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BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION 1910
NATURAL HISTORY REPORT

BRITISH MUSEUM NATURAL HISTORY

GEOLOGY. VOL. II. No. 1

THE VOLCANIC ROCKS OF THE ROSS ARCHIPELAGO

ERRATA

The calculated figures for cation per cent, equivalent norm, 'Niggli values' and 'Basis' (Tables Ic-f, pp. 38–39) for the 'Phonolitic trachyte' from Scott Island, analysed by G. T. Prior, should read as follows:—

Table Ic

CATION PER CENT

SiO_2	50·3
TiO_2	0·46
$\frac{1}{2}Al_2O_3$	20·85
$\frac{1}{2}Fe_2O_3$	1·19
FeO	4·90
MnO	
MgO	0·66
CaO	3·42
$\frac{1}{2}Na_2O$	13·58
$\frac{1}{2}K_2O$	4·18
$\frac{1}{2}P_2O_5$	0·11
TOTAL	99·61

Table Id

EQUIVALENT NORM

Q	—
Or	20·90
Ab	40·80
An	7·75
Ne	16·26
Wo	3·36
En	0·50
Fs	2·86
Fo	0·61
Fa	3·62
Il	0·92
Mt	1·79
Hm	–
Ap	0·3
TOTAL	99·67
Or	30
Ab	59
An	11

Table Ie

'NIGGLI VALUES'

si	172
al	35·3
fm	23
c	11·6
alk	30
ti	1·5
k	0·24
mg	0·1
c/fm	0·5
qz	−48
p	0·17

Table If

'BASIS'

Z	—
Cp	0·27
Ru	0·43
Kp	12·55
Ne	40·7
Cal	4·64
Cs	2·80
Fo	0·98
Fa	7·33
Fs	1·79
Q	28·65
TOTAL	100·14
L	57·89
M	12·90

I. THE DISTRIBUTION OF THE VOLCANIC ROCKS

This seventh number of the Geology reports on the British Antarctic ('Terra Nova') Expedition* deals with the volcanic rocks collected on Ross Island and also with the few specimens obtained from two of the very rare exposures of volcanic rocks on the mainland opposite Ross Island in the Koettlitz and Ferrar Glacier regions.

The notes on the distribution of the volcanic rocks are compiled chiefly from Professor Frank Debenham's published account of *The physiography of the Ross Archipelago*† and from his field catalogue and labels. Other sources of information are acknowledged in the text.

It seems appropriate to begin the description of the volcanic rocks with those collected on the higher levels of Mount Erebus as so much interest attaches to this active volcano in the midst of the snow and ice of the Antarctic. The specimens were collected in 1912 on what was known as the 'summer trip' under the leadership of R. E. Priestley [now Sir Raymond].

A full description of those parts of the active crater and the older craters so far as they were accessible to climbers was given by [Sir] T. W. Edgeworth David and Priestley,‡ and further details were added in 1923 by Professor Frank Debenham, who was one of the party of six to make the ascent in December 1912.

The specimens from the highest levels are loose feldspar crystals and masses of brown pumice. The manner in which these crystals occur has been well described by David and Priestley (op. cit. p. 213), and the character and shape of them as well as of the pumice are shown in two plates in their account of the mountain (op. cit. pl. 64 and 65) and in a photograph of two of the specimens brought back by the Terra Nova Expedition (pl. 1, fig. 1).

Describing the cinder cone in the active crater in 1912, Debenham writes: 'On the north-east side there was a small lava flow, but elsewhere the cone is formed of the spongy-brown pumice and the detached felspar crystals which every small outburst blows high into the air' (op. cit. p. 37).

The feldspar crystals, generally referred to as anorthoclase, were described and analysed by E. D. Mountain, who showed that they are better described as potash-oligoclase. Further reference to them will be made in the detailed petrography. The manner of their occurrence is similar to that of the anorthoclase crystals found at high levels on Mount Kenya, where they are associated with brown phonolitic glass similar in composition to the brown pumice of Mount Erebus.*

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* Previous numbers 1–6, published between 1914 and 1924, constitute volume 1 of the Natural History Report, Geology.

† Debenham (F.), Brit. (Terra Nova) Ant. Exp. 1910–1913, The physiography of the Ross Archipelago, 1923, pp. 33–7.

‡ David (T. W. E.) and Priestley (R. E.), Brit. Ant. Exp. 1907–9, Geology, vol. 1, 1914, pp. 210 *et seq.*

The freshest looking kenyte lava collected by the 1912 party is the slaggy kenyte from Hooper's Shoulder, a very prominent black pyramid of rock which stands out sharply against the background of ice at about 6,000 feet and some five miles distant from the central cone. The cone itself is about 300 feet high. Debenham (loc. cit. p. 33) says of this outcrop: 'In many places the lava is of the ropy type in quite small flows, many of which have not reached the base of the cone. In other places there are hollow columns of the slaggy lava as though the gases had penetrated these as funnels, while the mass was still plastic. It is obviously of very recent date, . . . and it seemed that the whole cone was formed of the same material and was probably produced in a comparatively short time.'

The glass of this lava in the hand-specimens is black and iridescent, and the lozenge-shaped feldspars, commonly about 1 × 0·3 cm. in cross-section, range up to 3 or 4 cm. in length [D22O].†

At less than half a mile from the present cinder cone of the active crater indications were found of a third crater, the active one being the fourth. The third crater is marked by a semicircular ridge which is well developed on the western side. The only specimens collected are rough crystals of feldspar thickly coated with scoriaceous brown glass.

The second crater is a more prominent feature and is clearly shown on the plane-table chart from which the excellent map (op. cit. map II) was prepared.‡ This crater is: 'the most complete and massive of the four which can be recognised. The sides of this crater are formed entirely of flows of lava. . . . On the north-west side of the mountain the rock forming the ridges of lava is a light-grey kenyte with large crystals of pyroxene in it as well as of felspar, but as one approaches the col between The Fang and Erebus the grey gives place to black, also with large crystals but with its felspars matted and star-shaped instead of the usual lozenge type' (op. cit. p. 35).

Specimens which would seem to represent rocks from this second crater rim are those from the ridge above Station E identified as Point 7650 about midway between Black Cone and Sulphur Cone.§

There are five specimens of kenyte from this ridge:

D5O. A dark grey kenyte with a wholly glassy base.

D7O. A dusky green-grey|| kenyte with a holocrystalline groundmass. The crystals of pyroxene in this rock to which Debenham refers in his field description quoted above are aegirine-augite. There are smaller insets (phenocrysts) of olivine.

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* Smith (W. Campbell), Bull. Brit. Mus. (Nat. Hist.), Mineralogy, vol. 1, No. 1, 1950, p. 9.

† Numbers in brackets [ ] are specimen-numbers. D refers to Debenham's catalogue.

‡ Reproduced in part as Map I in this number. See folder in back cover.

§ See inset map of the summit of Erebus. Brit. (Terra Nova) Ant. Exp., 1910–1913, map II.

|| Names used for colours of the hand-specimens and of minerals in thin section are based on Ridgway (R.), Color standards and color nomenclature. Washington, 1912.

This is a very good representative kenyte and resembles some that Debenham collected at Cape Evans [D26 and 68E].

D11O, D12O, D13O. Kenytes in which some kind of alteration has affected the pyroxene and olivine crystals, reddening them and rendering them quite turbid. This alteration imparts a deep brownish drab colour to the whole rock. Similar reddened specimens were found at Point 7650 (Station E) [D11E, D12E] associated with grey kenytes. A loose, weathered block of the same colour was collected at Lower Fang.

The black lava with star-shaped groups of feldspar found by Debenham on the approach to the col between The Fang and Erebus mentioned above clearly corresponds to the specimens [D1O, D2O, D16O] from the moraine at the top of Crater Glacier, the small glacier between The Fang and the mountain itself. These are porphyritic olivine-basalts with abundant slender, lath-shaped insets of labradorite-feldspar often, as Debenham records, in star-shaped groups. The specimens from the top of Crater Glacier are associated also with glassy kenyte [D16O] of a type containing very small crystals with the form of leucite, first observed by Dr. Prior in specimens collected by Ferrar on the Discovery Expedition of 1901–4.

The Fang is a ridge some 3 miles in length running roughly east and west. Debenham regards it as a huge remnant of the oldest crater rim. He writes (op. cit. p. 34): 'Its highest point, the Upper Fang, is 10,400 feet in height and is formed of a series of buttresses and cliffs of coarse tuff with pinnacles on its summit. A very similar buttress, the Lower Fang, 9,300 feet, is found a mile to the west. The whole of the ridge is roughly bedded, but is formed almost entirely of fragmental material rather than of lava flows.'

The specimens from the moraine below Old Fang [D24O] are all 'olivine-basalts'*, to use a general field term, and those from Lower Fang [D20O] are a varied assemblage of porphyritic olivine-basalt fragments and small bombs out of the tuffs of which also there are several large specimens. Among the basalts at these two localities are some with star-shaped groups of feldspar insets and numerous spherical vesicles like those from the head of Crater Glacier mentioned above. Others have conspicuous small black insets of pyroxene as well as the more numerous lath-shaped feldspars.

Another prominent outcrop at which specimens were collected is Abbott's Peak, a pyramidal cone about 5 miles WNW. from The Fang and at 5,840 feet, about the same level as Hooper's Shoulder. This had been thought to be another parasitic cone, but Debenham (op. cit. p. 34) considers it is another part of the old crater. His observation in the field was that the coarse tuffs and lavas of which it consists were similar in most respects to the rocks found in The Fang. In fact, several of the specimens from this cone are trachytic rocks perhaps intermediate in character between the phonolitic trachytes and trachydolerites [D9O, D19O]. The rocks, which in hand-specimens look like vesicular basalts [D18O, D29O], are olivine-basalts not quite like those of The Fang but rich in brown hornblende and a greenish pyroxene (see p. 80).

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* These 'basalts' all carry nepheline in the groundmass and hence are closely allied to rocks usually called 'basanite', but the name 'olivine-basalt' will serve well enough as a general term in this section of the report.

Retracing the routes followed from Cape Royds by both the 1912 and the 1908 parties, one notes that up to about 2,400 feet both routes were the same following a low ridge formed by a line of outcrops. Most of these, according to Debenham (op. cit. p. 33): 'represent the higher portions of definite flows of lava which have come from the main crater, but there are also some minor cones which are parasitic'. Many of these outcrops between Turret Cone at about 1,400 feet (op. cit. map III) and Station A, Point 910, map II) are marked on Debenham's plane-table chart as kenyte and so are two on the 1908 party's route at 2,440 and 2,875 feet.

The low ridge and line of outcrops meets, at about 650 feet, a low ridge of fine moraine (op. cit. map III). Three miles south of this point is Mount Cis, a denuded cone about 20 feet high, and about a quarter of a mile to the west of it is a small parasitic cone, Point H, while about the same distance to the south of it is another, Point G. (These are shown just below the 600 feet contour on map III.) Another was noted in 1908 by David and Priestley about 400 yards to the NNE. of Mount Cis (op. cit. 1914, p. 221).

Mount Cis consists of phonolitic trachyte. The cone itself is described by David and Priestley (op. cit. p. 220) and the rocks and their interesting inclusions are described by H. I. Jensen* and by J. Allan Thomson.† Both Priestley and Debenham made collections‡ of these inclusions representing all the varieties described by J. A. Thomson (p. 25).

The other cones are kenyte- and basalt-tuffs. The tuff from Cone H [D27O, D20R] has a fine-grained, drab-coloured base and contains black and red fragments of kenyte and of basalts, both aphanitic and porphyritic varieties, and many loose fragments of feldspar. A precisely similar tuff is that from a parasitic cone in the collection made by David and Priestley in 1908 [BM. 1911, 135, 12=J12].§ A similar mixture of kenyte and basalt fragments was found in the tuff cone 400 yards NNE. of Mount Cis. The specimens from Cone G [D25O, D23R] consists of large pieces of black, glassy kenyte, many small lapilli of black glass, and loose, mostly yellowish, altered, lozenge-shaped feldspars.

The outcrops round these parasitic cones and round Mount Cis marked on Debenham's plane-table chart are all shown as 'kenyte'. Along with the outcrops between Mount Cis and Turret Cone (op. cit. map III) they belong to what Debenham has described as the upper zone of lava-flows and parasitic cones in the Cape Royds district (op.

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* Jensen (H. I.), Report on the petrology of the alkaline rocks of Mount Erebus, Antarctica. Brit. Ant. Exp. 1907–9, Geology, vol. 2, 1916, pp. 94–100.

† Thomson (J. Allan), Report on the inclusions of the volcanic rocks of the Ross Archipelago. Brit. Ant. Exp., 1907–9, Geology, vol. 2, 1916, pp. 134–6 and 143–4.

‡ Numbers 8–90 in Priestley's and specimens marked C in Debenham's collections.

§ David and Priestley, op. cit. p. 221.

cit. p. 13). This zone is separated from the coastal belt of volcanic rocks by a broad belt of morainic material carrying mainly volcanic rocks mixed with some mainland rocks, plutonic, sedimentary, and metamorphic types.*

The coastal belt from Horseshoe Bay to Cape Barne, a distance of some four miles in a direct line, consists for the most part of lava-flows in situ, with a thin covering of moraine (Debenham, op. cit. p. 13). David and Priestley (op. cit. p. 218), noting that the true structure of the district is largely obscured by extensive patches of morainic material, find evidence that some of the older kenyte lavas are traversed by a network of dikes. They observed distinct stratification in the volcanic rocks at the landing place on the south side of Flagstaff Point with steep dip seawards. Some dikes they saw stood out prominently 'such as the one at the Penguin Rookery, and that which divides up Blue Lake'.

All the specimens from this coastal belt in the Cape Royds district collected in situ by the Terra Nova Expedition are kenytes. The erratics include basalts of several types and a phonolitic trachyte [D9R, D18R].

At the 'point beyond Horseshoe Bay', that is on the north side of it (see Fig. 1), Debenham records flows of brownish kenyte. D9R and D10R are from this point. They are true kenytes, dark grey on freshly broken surfaces, but they have a partly glassy groundmass somewhat different to that of the more common black, glassy kenytes.

Nearer Cape Royds Debenham collected from a flow [D1R] 50 yards west of High Peak and from the base of the cliff above Blacksand Bay [D14R], where he records three distinct lava-flows superimposed upon one another with glassy and slaggy kenytes in between and exhibiting all the characters one would expect of flows which had come some distance. This [D14R] is a typical kenyte and so is a black, glassy, and vesicular specimen with ropy surface structures from the valley above Blacksand Bay [D3R]. Other typical kenytes were collected at points above Backdoor Bay [D6, 12, 15, 16R] and from Point B some $1\frac{1}{4}$ miles north of Cape Royds [D13R] in the area marked 'irregular lava-flows' (op. cit. map III).

Commenting further on the fresh appearance of the kenytes in this area, Debenham wrote (op. cit. p. 14): '. . . there are places on the cape where the surfaces of the lavas are so glassy, the flows themselves so thin, and the directions of flow so diverse, that it is difficult to reconcile them with an origin 10 or 15 miles away. No signs of local kenyte vents are to be found on the lower zone and none of sufficient size to give rise to extensive flows anywhere on the area'. David and Priestley had suggested (op. cit. p. 218) that Cape Royds is probably situated near an independent point of eruption of the nature of a parasitic cone.

Farther south towards Cape Barne kenytes form the massive lava at the sides of Deep Lake. They are represented by grey kenytes [D26O] from the base of the cliff on the west side of the lake, and [D21R] the lower of two flows forming a cliff face in Deep

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* See Woolnough (W. G.), Petrological notes on some of the erratics collected at Cape Royds. Brit. Ant. Exp. 1907–9, Geology, vol. 2, 1916, pp. 169–86.

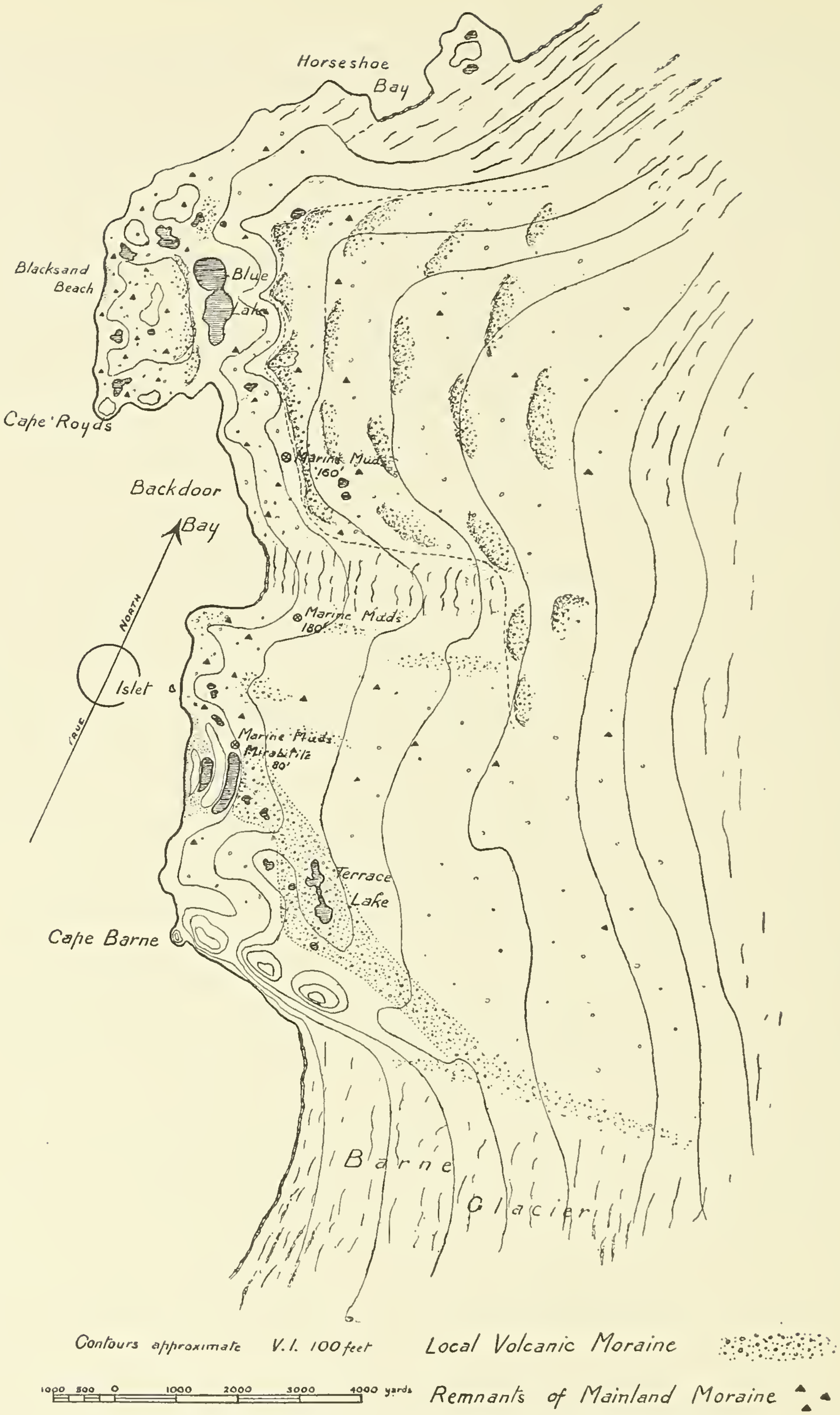

Fig. 1.—Map of the Cape Royds district from Horseshoe Bay to the Barne Glacier.

Lake Valley. Beyond Deep Lake at Cape Barne itself and to the east of it is: 'a well-defined centre of basalts, of which the denuded cones of three vents are still prominent, and the plug or consolidated vent of one of them remains as a distinctive mark from seaward anywhere in the vicinity, and is known as Cape Barne pillar' (Debenham, op. cit. p. 15, pl. 7). The basalts from these outcrops were described by Jensen (op. cit. pp. 112–13). They are represented by two specimens, D24R from Middle Dome and D28O from Cape Barne Pyramid.

There has been some difference of opinion as to the relation of the Cape Barne basalts to the older kenytes in their vicinity. David and Priestley (op. cit. p. 219–20) regard the basaltic belt as strongly intrusive in the older kenyte lavas, and they show them as such in a section in their geological map (op. cit. pl. 95). They recorded several burnt and reddened fragments of kenyte lying at the foot of a hill of agglomerate east of Cape Barne Pillar, and one of these kenyte fragments was found in place cemented in the agglomerate. Secondly, they considered that the lines of kenyte boulders marking the outcrop of basaltic tuffs and agglomerates farther inland from the cape 'have been weathered out from the basalt, and have not been deposited on the beds by glacial action. Many of these kenyte boulders were burnt a brick red and coloured with sulphur, as if they had been part of the lining of the vent by which the basalt was poured out, and had been torn off by the explosive action of the steam and gases accompanying the eruption' (p. 220). They considered on this evidence that the basalts of Cape Barne were younger than the older beds of kenyte, but that 'the kenyte of the newest of the Erebus craters is more recent than the basalts of Cape Barne' and that the lava of Cape Barne is the product of a subsidiary reservoir.

Debenham, on the other hand, while holding for certain reasons (not precisely stated) that the basalt would have penetrated flows from Erebus, considers on the field evidence that the Cape Barne basalts are definitely older than most of the lavas composing the district but probably much younger than the trachyte remnants of Mount Cis. He did not find any kenyte fragments in the basaltic tuffs on Cape Barne, and he found on the north side of the basaltic area, i.e. inland from Cape Barne, that the basalts are overlain by kenyte flows (op. cit. p. 16). From the general appearance of the landward sides of the basaltic tuff cones he compared them in age with some of the older crater cones of the Hut Point Peninsula, another basalt area to which full reference will be made below.

Farther round the coast on the south side of the Barne Glacier is the low promontory of Cape Evans (formerly The Skuary, see Fig. 2). A sketch-map of the cape and many illustrations of its rocks and glaciers is given in a memoir by Dr Griffith Taylor* in which the physiography of the area is described, and Professor Debenham added a short account of the rocks and their relation to other outcrops along the coast in his slightly later memoir (op. cit. p. 17). A fuller account of the moraines and brief mention of the country rock was given by David and Priestley (op. cit. p. 227). They describe the country rock as a compact, brownish kenyte somewhat lighter coloured than those met with at Cape Royds, and with rather lighter coloured porphyritic feldspars. They noted that the feldspars weathered out of the rocks* were so unaltered, chemically, that they were almost transparent and a very light yellowish colour, and that the cliffs in places from 80 to 100 feet in height seemed to consist of lava-flows one above the other, and with scarcely any dip. Most of the exposed land, about 2½ square miles, is covered with morainic material that seems to be mainly of local extraction. Debenham found in the shelf of ice and moraine behind the cape, peculiar loose and fine-grained tuffs. These, he considers, are definite evidence of deposition in water higher up the mountain and that

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* Taylor (Griffith), The physiography of the McMurdo Sound and Granite Harbour region. Brit. Ant. (Terra Nova) Exp., 1910–1913, 1922, fig. 82 and pls. 76–98.

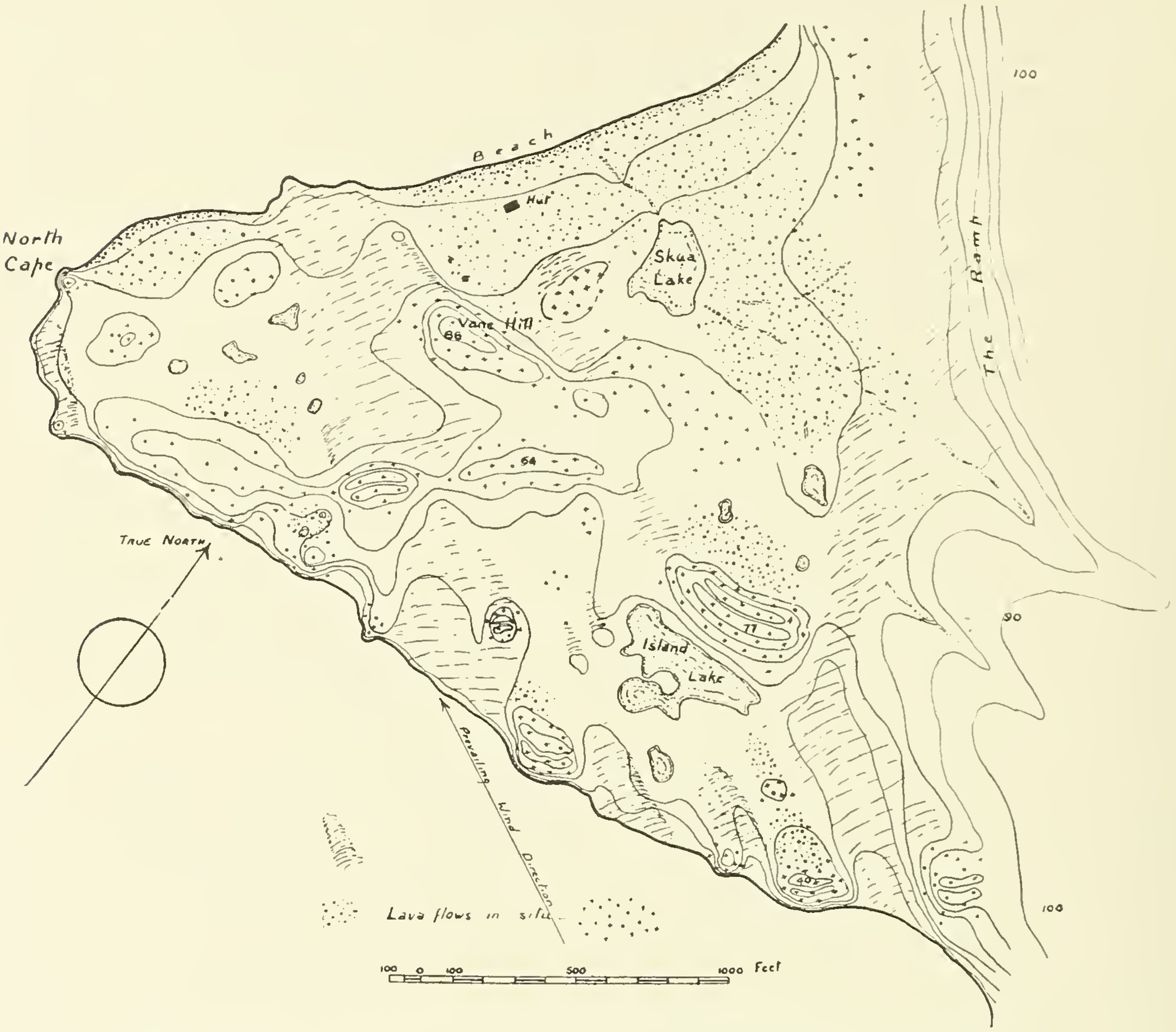

FIG. 2. Map of Cape Evans based on the plane-table survey by F. Debenham.

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* The weathering of the rocks resulting in the release of the feldspars was later again observed by Griffith Taylor, who referred to the product as 'rock meal' (op. cit. p. 40 and pl. 48).

the water may have been due to melting of ice by volcanic action. He suggests that the lavas are typical kenytes but of a more acid character than those of Cape Royds (op. cit. p. 17 and pl. 8). This may have been suggested by the observation already made also by David and Priestley that they are lighter coloured, but, to judge from the hand-specimens, these lighter rocks are not the most typical. All the specimens from Cape Evans in Debenham's collection, whether in situ or erratic, are kenytes. They range in colour from black to grey and greenish grey and through various shades of red. All show abundant insets of feldspar of the characteristic rhomb form (Pl. 1, Fig. 1). The lava in situ under the Barne Glacier [D8E] is dark grey and so is that from the base of the outcrop at The Slipper [D26E]. A black glassy type forms the upper edge of the same outcrop [D27E]. Red and brown kenytes are erratics from close to the hut [D5E] and the upper slope of the Barne Glacier moraine [D11E]. The very light-coloured kenytes are quite peculiar. Some have a devitrified glassy base, but others have a holocrystalline groundmass rather unusually coarse-grained and all carry abundant very pale cream-coloured feldspars of the characteristic kenyte shape. These rocks may have some of the characters of sanidinites in trachytic lavas and may occur as inclusions in the more usual types of kenyte lava (p. 53 and Pl. 2, Fig. 1).

The last and most southerly rocky outcrop still forming part of the main mass of Erebus is in the Turk's Head district. Here two isolated points of rock, Seal Rookery and Turk's Head to the south-east, are separated by a glacier. The section of the cliff at Turk's Head was described in detail by David and Priestley (op. cit. p. 226). It is in general confirmed by the description given by Debenham. Pictures of the cliffs are given in Griffith Taylor's account of the physiography of McMurdo Sound as well, and he also described the effects of frost and wind action there (op. cit. pp. 41–2, pl. 37, 55, and 56). Debenham says: 'The most prominent rock is a peculiar tuff [D10T] or agglomerate which appears to form what may be called the foundation of the two capes as far as can be seen. It . . . may in general be described as a massive tuff with comparatively little matrix, the whole having a reddish hue and occurring in thick masses rather than in beds or definite strata.' He notes that it is quite different from any of the tuffs found on the west coast of Ross Island and that the 'kenyte' which constitutes the bulk of its fragmental material is also distinct in character. The blocks of lava in this agglomerate are both large and very numerous. David and Priestley noted that many of them are 18 inches to 2 feet in diameter. These authors and Debenham remark that the feldspar crystals within the rounded blocks of lava have a well-marked concentric arrangement (Debenham, op. cit. pl. 11 and p. 23).

The coarse agglomerate on Turk's Head is 'overlain in the direction of Erebus by a series of dense kenytes dipping to the north and west'. David and Priestley recorded a dip of about 45° to the north-west. The feldspars in these lavas are 'in shape very flattened and plate-like, arranged with an orientation usually parallel to the dip of the flows, but occasionally arranged in a way which gives a beautiful curvilinear flow structure to the rock' (op. cit. p. 226).

The specimens of lavas with tabular, platy feldspars from Turk's Head are porphyritic (feldspar-phyric) 'olivine-basalts' or basanites. Examples are a glassy variety [D1T] collected by T. Gran, D4T from the east summit cone, D8T from the base of Turk's Head, and D9T, a small, rounded block with a black, glassy base from the tuffs at the summit. Jensen described some of these rocks with tabular plagioclase insets [J11] from David and Priestley's collection as 'basic kenytes' (op. cit. p. 108). In addition to these 'basalts' there are also specimens of typical kenytes from the summit [D2T], black, glassy kenyte, and two others, red-weathered and vesicular [D5T], found in the debris on the summit by Tryggve Gran. It is not stated that these were in situ, but it may be noted that tuff from the summit [D7T] contains crystals of anorthoclase.

The tuffs range in ground colour in hand-specimens from pinkish buff to deep olive, and from pale brownish vinaceous to deep livid brown. In the field the prevailing colour is evidently a red hue. One from the summit has small lapilli of black glass and crystals of anorthoclase in a deep olive base and recalls the appearance of some tuffs from Cape Royds [D7R] and perhaps that from cone G [D20O]. Somewhat similar are the specimens from the base of Tuff Bluff taken within a foot of each other and showing great variation in grain-size but all agreeing in being composed of angular fragments of brown glass and feldspar, in this case plagioclase.

Debenham has remarked that both rock fragments and matrix in these tuffs have points of resemblance to the tuffs and included blocks of the The Fang, part of the oldest crater of Erebus, but he thinks that they must have had a distinct origin, because such enormous blocks of lava as they contain could hardly have been thrown far from the eruptive centre. On the western and smaller promontory (Seal Rookery?) he records tuffs with a steep dip to the north and a thin lava-flow has a similar dip (op. cit. p. 23). As noted above, at Turk's Head he records lava dipping north and west, 'making more conclusive the evidence that all the material of Turk's Head originated in the direction of the Erebus Bay Glacier Tongue', that is, to the south and south-east.

The Dellbridge group consists of four small islands: Inaccessible, Big and Little Razorback, and Tent. The most northerly of the group, Inaccessible Island, is only about 2 miles to the south of Cape Evans and 6 west of Turk's Head. David and Priestley record rock-specimens secured on brief visits to the island by Sir Ernest Shackleton, who walked there from Cape Royds, and by two parties of his expedition in 1908. They report the rocks as trachytes, basalt, kenyte, and tuff. The trachyte collected in situ by Sir Ernest Shackleton was from a flow beneath basalt. In these reports the name kenyte is given indiscriminately to both the typical kenyte of Mount Erebus and the 'basic kenytes' with thin platy feldspars. The rocks in Debenham's collection are trachytes and basalts or basanites with abundant tabular feldspar insets and thus resembling Jensen's 'basic kenytes' in hand-specimens. There are no true kenytes in Debenham's collection from the island and only one 'basic kenyte' [D25I] (see p. 74). The appearance of Inaccessible Island and its cliffs is well shown in two plates in David and Priestley's memoir (op. cit. pl. 72 and 73) and in two figures in Griffith Taylor's memoir (op. cit. figs. 18 and 20). Debenham has described the general structure of the island, as best seen from the south side. The lower 200 feet of the slopes are formed of a dark 'kenyte' in many separate flows. Above this is another 200 feet of a blue-grey 'kenyte', the two being separated by a thin band of fine-grained black lava. The blue-grey upper lavas have a dip of 10° to 30° to the north-west, and they form the whole of the northern slopes of the island. A few thin beds of red and yellow tuff can be seen low down on the southern side bedded between the lava flows. He notes that many of the lavas are 'trachytic in structure and more acid than most of the kenytes', and that the dips of the lavas all point to a centre of eruption to the south and west of the island where there is now no sign of land. Both facts, he considers, indicate that the lavas are the product of an old centre of eruption much older than that which gave rise to the lavas of Cape Royds, Cape Evans, and, of course, Erebus (op. cit. p. 18).

The specimens referred to in the field description above as 'kenytes', that prove on examination under the microscope to be basalts or basanites, are:

D5I	Typical grey kenyte (salt encrusted) of northern lower cliffs.
D6I	A glassy type from the eastern cliffs, 50 feet up.
D10I	From upper part of the island.
D20I	Summit, west end, in situ.
D26I	Lava, at base, near couloir.
D27I	From upper slopes.
D30I	At top of east peak, in situ.

The trachytoid phonolites are, with the exception of D3I from the lower northern slopes, all from the eastern end of the island and, in general, low down.

In addition to the lavas a number of rather coarse-grained inclusions from the lavas were also collected.

It was at the eastern end of the island that Debenham (op. cit. p. 18) noted: 'a confused mass of lavas and tuffs which has the appearance of a pipe or plug of a vent; but . . . may simply represent heavy settlements or local disruptions which have destroyed the otherwise uniform lie of the lavas'.

Tent Island, somewhat less than a mile south of Inaccessible, has also been described by Debenham, and a sketch-map shows its surface features and the distribution of scree, gravel, and rocky outcrops (op. cit. p. 18 and fig. 6). The lower 50 feet of the cliffs all round the island shows coarse tuff containing boulders which Debenham described in the field as 'grey kenyte'. At the NW. end of the island these boulders [D43E] are all dark grey to black or red-weathered somewhat vesicular basalts, or basanites, with small insets of feldspar. The lavas above and below the tuff on the west side [D44 and 45E] are dark grey to black basalts, or basanites, with tabular feldspars in a trachytic textured groundmass. Another outcrop beside one of the two small deltas on the west side is a dark grey trachyte [D21E] and fragments from the tuff on the west side, and the 'basalt' underlying the tuff are also trachytes, somewhat paler, olive-grey in colour [D24E]. At the SE. end the lava above the tuff is a glassy basalt with abundant plagioclase insets [D47E], and similar rocks were found forming the base of the cliffs on the south side [D42E], intruding through the tuff on the SW. side [D46E], forming the summit above a gully on the west side [D39E], and on the south summit [D18E].

The tuffs themselves are represented in the collection by specimens from the west side and SW. end [D37E and D38E]. They are dark grey, rather friable, and full of fragments of feldspar, pyroxene, olivine, small blebs of black glass, and many lapilli of dense or glassy rocks. About twenty specimens were collected by C. S. Wright, glaciologist to the Expedition, and many of these are 'bombs' from the tuffs or inclusions in the lavas (Pl. 2, Fig. 1) such as were also found on Inaccessible Island. Debenham has given an excellent photograph of the coarse tuff of Tent Island (op. cit. pl. 9).

Four specimens from the island [D61E] were collected by Demetri. These surprisingly include two kenytes and a 'basic kenyte' as well as a glassy basalt. True kenytes are not otherwise found in the Dellbridge group,* but according to Debenham 'grey kenyte . . . similar to, but not exactly the same as, the upper grey lavas of Inaccessible' surmount the tuffs at the northern end of the island† (op. cit. p. 19). Professor Debenham was inclined to regard Tent Island and Inaccessible Island as remnants of the same former large volcanic cone.

Only 2 miles east of Tent Island but apparently structurally quite distinct from the two larger islands are the Razorback Islands, Big and Little. The lavas of Big Razorback are olive-grey to black vesicular trachytes, some showing many feldspar insets. The darker specimens have a glassy base and are vesicular [D30E]. A remarkable turret-shaped mass at the western end (op. cit. pl. 10a and fig. 7) may be one of the original vents. It consists of the same kind of trachyte as those from the base of the cliff both below the Turret [D29E] and in the middle of the island [D31E]. Debenham has also recorded irregular masses of coarse red and brown tuff at the base of the Turret and a fine-grained tuff bed half-way up the cliff among the lavas at the eastern end.

The specimens from Little Razorback, from the summit [D35E], and from the base, at the west and at the south-west end [D33 and 34E], are olivaceous black and dark quaker-drab, somewhat vesicular lavas which must be classed as basalts, or trachybasalts, rather than trachytes of any sort (see p. 88). Only the paler, deep mouse-grey porphyritic lava [D32E] from the base at the east end (named kenyte in the field) can be classed as of the same kind as the trachytes of Big Razorback. Debenham writes of this island (op. cit. p. 22): '. . . though over half a mile distant [from Big Razorback, it] is strikingly similar both in shape and structure. The flows of trachyte are thinner and show a dip of two or three degrees away from the larger island. Seven or eight separate flows of lava make up the whole of the visible part of the island, those at the base being thicker and a deeper grey than the upper ones (see pl. 10 (*b*)). Inter-bedded between the flows are thin irregular bands of red rubble, which represent surface debris rolled over and imprisoned between the flows. The latter show excellent examples of upper and lower cooling surfaces fine-grained, vesicular and rough. From the comparative thinness we may suppose that the trachyte had a high degree of fluidity. We know nothing of the sea floor between the two islands except that, one-third of the way from the smaller to the larger, there was a berg about 20 feet high, which had grounded, from which it seems legitimate to presume a submarine ridge connecting the two'. In point of age, Debenham suggested they should be correlated with Mount Cis and with the trachytic rocks of Observation Hill on Cape Armitage, 12 miles to the south.

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* In Tent Island one of the boulders [D43E] in the tuffs at the north-west end and one weathered block from the summit of Inaccessible Island [D25I] may be 'basic kenyte'.

† The only specimens in the collection are inclusions [D17E and D19E] described as 'in typical kenyte of the northern half' of the island. The host rock may have been a porphyritic basalt or 'basic kenyte' (see p. 54).

Cape Armitage is the southern point of Hut Point Peninsula. Close to the cape and rather separated from the rest of the peninsula is Observation Hill, 760 feet, now well known to many as the site on which was erected in January, 1913, the large wooden memorial cross to Captain Scott, Dr. E. A. Wilson, Captain L. E. G. Oates, Lieutenant H. R. Bowers, and Petty Officer E. Evans, who died on their return from the Pole in March, 1912. This hill consists of trachytes. They were described by G. T. Prior from material collected by Ferrar* in the Discovery Expedition, 1901–4, and further material was collected by Debenham and outcrops were mapped on the plane-table chart (Map II). Debenham also found trachyte outcrops at two points on Crater Heights, a plateau between Crater Hill and Observation Hill. These trachytes are in kind related to those found on Inaccessible Island and also, but perhaps less closely, to the trachytes of Mount Cis and Abbott's Peak. They are thought by Debenham to belong to an early phase of the vulcanicity. He is inclined to regard as still older 'the turret-shaped mass of Castle Rock rising some 400 feet above the general level of the peninsula'. This consists of tuffs. They are yellowish ochraceous buff to tawny or ochraceous tawny in colour and contain fragments of dense, aphanitic, black basalts. In hand-specimens they recall in appearance some palagonite-tuffs. It is doubtful if their age relative to the trachytes and later basalts can be guessed from their composition. Prior described the specimens collected by Ferrar at Castle Rock as palagonite-tuff, and Ferrar recorded basalt from the lower part of the crag and as fragments strewing the summit.

Debenham found palagonitic basalt-tuffs [D23H, D28H] at a much lower elevation, between 250 and 400 feet above sea-level, at Boulder Cones, $\frac{3}{4}$ mile west of Castle Rock, associated with olivine-basalts, 'of the kind usually associated with the later stages of a cycle of eruption when magmatic differentiation has proceeded towards its limits; nodules of pure olivine are common, and the basalts are dense and heavy' (op. cit. p. 25). Back northwards along the coast towards Turk's Head and $5\frac{1}{2}$ miles north of Boulder

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* Ferrar (H. T.), National Antarctic Exp., 1901–1904, Nat. Hist., vol. 1, Geology, 1907, p. 12.

Cones at Hutton Cliffs other palagonitic basalt-tuffs occur [D21H]. This occurrence was fully described by Ferrar (op. cit. p. 11). Specimens [D21H] were collected by Tryggve Gran. They are tuffs containing many dark fragments of basalt. The ground colour varies from greenish-yellow to dusky olive-green and deep olive. About 1½ miles SW. of Hutton Cliffs, on Turtle Rock (Turtle Back Island of the Discovery reports), 'the main mass of the island consists of fine-grained fragments of olivine-basalt (449)' and 'black augite-olivine nodules are common' (Ferrar, op. cit. p. 14).

All the other rocks collected in situ on Hut Point Peninsula are black, dense olivine-basalts and their scoriaceous vesicular equivalents. At many places marked on the plane-table chart, one of which is Sulphur Cones, the lavas contain many nodules of olivine or other 'gabbroid' rocks [D24H] (p. 80). It may be noted here that a basalt from Half Moon Crater, south of Castle Rock, is hornblende-bearing [249]. Many loose crystals of augite were found on the north-west side of Observation Hill [D10H] and in lavas at the top of the Ski Slope [D11H]. The olivine, pyroxene, and gabbroid nodules in the basic rocks (basalts and limburgites) of Hut Point were described by G. T. Prior* in 1907 and by J. Allan Thomson† in 1916: Debenham has noted in addition that 'numerous examples of sedimentary inclusions have been found on the peninsula, indicating that the fissure formed in the old sedimentary rocks was widened by masses being torn off by the ascending magmas' (op. cit. p. 26).

East of Hut Point Peninsula Mr. Hodgson of the Discovery Expedition collected bedded yellow tuffs and some fragments of vesicular basalt at Sultan's Head, and coarse yellow tuff, red vesicular basalt, and a basaltic bomb from the V-Cliff (V-Cliffs Hogsback, Ferrar, op. cit. p. 10).

East again of these points no other accessible rock outcrops are known round the coast of Ross Island until one comes to Cape Crozier, 50 miles ENE. from Cape Armitage, on the far side of the Ross Barrier. Debenham has described the geology of the cliff at Cape Crozier and of The Knoll above it (op. cit. p. 8). The Knoll is a volcanic cone. The face of the cliff, which varies from 200 to 400 feet in height, 'shows bedded lavas and tuffs, and towards the base are several lenticular patches of columnar basalt which were probably not surface flows but were injected from the main vent. The lava from The Knoll is a fine-grained basalt and on the surface are many volcanic bombs and other evidence of explosions on a small scale. The tuffs of the cliff are brown palagonite-tuff, composed of particles of the same basaltic kind of lava'.

'From the Knoll easy slopes of debris and lava lead to a group of hills round the large penguin rookery, some four miles to the north-west. Most of these are fairly recent parasitic cones which produced basalt, but a denuded cone, 1,400 feet in height, immediately to the south of the rookery, consists of a trachyte very similar in character to that of Observation Hill' (op. cit. p. 8 and pl. 1, 2, and 3). This trachyte dome was described by Ferrar and the rock and other specimens of trachyte were briefly mentioned by Prior (op. cit. p. 115). Ferrar had also described the palagonite-tuff of the cliff at sea-level at Cape Crozier [228 to 230]. Half a mile west of the rounded knoll of trachyte referred to above he records a boss about 900 feet high of which: 'the rock (176) is a limburgite containing red and green olivine-augite nodules' (op. cit. p. 11). Ferrar also records specimens collected by Dr. E. A. Wilson; basalt scoria [824] and limburgite [825] from cones on the east side of Mount Terror above the Ross Barrier; and from Crozier Cliffs columnar basalt [830], which forms the mass of the cliffs and reaches a height of 800 feet above sea-level; and a yellow trachytic rock [831] occurring in irregular lenticles in the mass of the cliff.

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* Prior (G. T.), National Antarctic Exp. 1901–1904, Nat. Hist., vol. 1, Geology, 1907, p. 107.

† Thomson (J. Allan), Brit. Ant. Exp. 1907–9, Geology, vol. 2, 1916, p. 131.

Lastly one may mention the northernmost point of Ross Island, Cape Bird. Mount Bird itself has never been visited. What little is known about it has been told by Debenham (op. cit. pp. 4, 5, and 11). At Cape Bird two landings were effected in 1909, Sir Douglas Mawson collecting a number of specimens of the rocks, mostly loose pieces. These have been described by H. I. Jensen (op. cit. pp. 118–26). Some of them were in situ from the agglomerate at the place where the landing was made.

Jensen describes alkali-trachytes, hornblende-bearing trachydolerites referred to kulaite, basanite, alkaline dolerite, and limburgitic dolerite. No kenytes were found in Mawson's collection, and this confirms Debenham's supposition that: 'there is no close relation between the magmas, and that the history of Mount Bird is in a sense distinct from that of the central mountain [Erebus]' (op. cit. p. 11). It is unfortunately a region very difficult of access either by land or sea. Lieutenant Macintosh and McGillan landed on the Cape on January 3, 1909, and without equipment or sleeping-bags they achieved the crossing to Cape Royds, 'a feat', as Debenham remarks, 'not lightly to be repeated'. Jensen (op. cit. p. 126) states that Prior recorded basaltic hornblende in certain basalts of Cape Bird, implying that the Discovery Expedition landed and collected there, but this is not so. It is probable that 'Cape Bird' is a mistake for 'Cape Adare'.

For information of the rocks in situ on other islands of the Ross Archipelago one must go to the report of the Discovery Expedition. Rocks were collected on several of the islands by Ferrar and others and were described by Prior. The islands concerned lie to the south of Ross Island. They are White Island, Black Island, Brown Island, and Minna Bluff, these last two connected by low isthmuses with the main mass of Mount Discovery.

White Island was visited by Sir Ernest Shackleton with Dr. Wilson and Ferrar in 1902. 'The only rock obtained from it in situ is a black hornblende-olivine-basalt (311), which occurs as a boss on the summit. One or two crateriform depressions occur on the lower portions of the island, and there seems little doubt that the whole island consists of volcanic rock' (Ferrar, op. cit. p. 14–15). On Black Island, adjacent to White Island on the west, Ferrar collected compact and vesicular basalts, a phonolite or phonolitic trachyte [530] and a yellow trachytic rock [609, 610]. Of this last Ferrar wrote: 'It appeared to be a dyke nearly a quarter of a mile wide breaking through the black basaltic rock' (op. cit. p. 14). Debenham states: 'The greater part of the island seems to be composed of basaltic lavas very similar to those of Hut Point, but on the eastern side there is one large occurrence of trachytic lava which is older than the basalt and bears probably the same time relation to it as does Observation Hill to Crater Hill' (op. cit. p. 29).

Brown Island, to the west of Black Island and adjoining Mount Discovery, was also visited by a party from the *Discovery*, and Ferrar collected: red vesicular basalts [605], a hornblende-basalt [608], a banded yellow rock (phonolitic trachyte) on the north side [598, 600], and a white phonolitic trachyte [606, 607] from the crater. The lower surface was covered with black, smooth, loose fragments of basalt [603] (Ferrar, op. cit. p. 15, and Prior, p. 115). The Dailey Islands, five small islands to the north of Brown Island, seem to consist of 'basaltic rocks of limburgite type [510]' (Ferrar, op. cit. p. 15).

Of Minna Bluff, Mount Discovery, and Mount Morning nothing is known except from distant observation. Specimens of basaltic and phonolitic rocks [619 and 622] were obtained by the Discovery Expedition from the south-east end of Minna Bluff (Ferrar, op. cit. p. 21), and Debenham has described the volcanic features both here and on Mount Morning and Mount Discovery (op. cit. pp. 30–1).

Although this part of the report is concerned with the Ross Archipelago, it is necessary to describe also the basalts from the few small exposures on the mainland opposite Ross Island that were investigated by Griffith Taylor and Debenham.

The likelihood of relatively recent basalts being found on the mainland had been indicated in 1907 by Prior's recognition of one of Ferrar's specimens [718] from the scree slope at Cathedral Rocks, on the south side of the Lower Ferrar Glacier, as a basalt that had a 'much closer relationship to the recent basalts of the Ross Archipelago than to the dolerites of the Ferrar Glacier' (Prior, op. cit. p. 106).

On the Terra Nova Expedition basalts were collected in two distinct areas: one up the Koettlitz Glacier valley; the other on the borders of the Taylor Glacier, west of the Kukri Hills. These basalt outcrops and the craters are briefly mentioned by Griffith Taylor in his memoir on the physiography of the region, and he remarks on their particular interest as affording evidence of eruptive activity on the mainland since the major glaciation of the continent.*

In the Koettlitz Glacier valley two craters are marked on map IV and a crater and a lava-flow are shown in a sketch panorama in Griffith Taylor's memoir. One of them, the crater, is 4 miles west of Heald Island. The lava-flow is between Howchin Glacier and Walcott Glacier. Taylor refers to the lava-flow as an irregular ridge of basic lava which marks the ridge immediately north of the Walcott Cirque Glacier (op. cit. p. 135, and pl. 141). He collected a few specimens from the lava-flow beside the Howchin Glacier, 2½ miles from Walcott Glacier [D3K, D5K], and a few specimens were obtained also from a moraine opposite Heald Island [D9K] and from 'Cape Olivine' [D13K].

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* Taylor (Griffith), The physiography of the McMurdo Sound and Granite Harbour region. British Antarctic (Terra Nova) Expedition, 1910–1913, 1922, p. 135.

In the Taylor Valley there are two outcrops of recent volcanics. One of these, referred to in Debenham's catalogue as Cheyenne Crater, is at 2,500 feet just above Lake Bonney and alongside the Rhone Tributary Cliff Glacier. The crater is shown in a telephotograph (pl. 121) in Griffith Taylor's memoir standing perched on the 'smooth glacial shoulder of the Taylor Valley' (op. cit. p. 135). The telephotograph was taken from Alcove Camp on the Taylor Glacier from which Debenham ascended to collect specimens from the crater [D8F, D16F], and from another ridge formed by a lava-flow on the opposite side of the Glacier.* This lava-flow is shown in a sketch-panorama (Taylor, op. cit. 1922, fig. 94) looking west up the Taylor Glacier from Bonney Riegel towards Solitary Rocks.

The purpose of this review of the distribution of the volcanic rocks has been to provide a background for the detailed petrography. It will be realized that much more detail as to field relations and modes of occurrence of the rocks is to be found in Professor Debenham's memoir on the physiography of the region and in the memoirs of Sir T. W. Edgeworth David, Sir Raymond E. Priestley, and H. T. Ferrar, to which so many references have been made above.

Summarizing briefly, the main groups of different kinds of volcanic rocks encountered are:

(1) The true kenytes of Mount Erebus exposed at many outcrops on the mountain and along the coast from Horseshoe Point by Cape Royds and Cape Barne to Cape Evans and probably also at Turk's Head.

(2) Phonolitic trachytes of several types, usually localized at denuded cones with an aged appearance. They are described from Mount Cis and Abbott's Peak on the slopes of Erebus, at Observation Hill on Hut Point Peninsula, and at Cape Crozier. Among the collections of the earlier expeditions they are represented also from Cape Bird, Black Island, and Brown Island.

(3) Basalts of several kinds which one can group conveniently under three headings:

(*a*) Basalts (or basanites) with abundant thin tabular plagioclase insets and, associated with these, other olivine-basalts with insets of plagioclase, augite, and olivine.

Rocks of this group were found on the ridge of the second crater of Erebus, at The Fang (on the third crater), in some of the Dellbridge Islands, and at Turk's Head.

(*b*) The basalts of Cape Barne, poor in olivine.

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* Taylor (Griffith) *in* Scott's Last Expedition, vol. 2, 1913, p. 197.

(*c*) Olivine-basalts and limburgites. These occur at Hut Point, Cape Crozier, Turtle Rock, Brown Island, Black Island, and possibly at Cape Bird, and on the mainland opposite Ross Island. Cape Bird also yielded specimens of a hornblende-basalt, referred by Jensen to kulaite. Hornblende-bearing basalts were also described by Prior from White Island [311], and from Brown Island [608], and one specimen was collected by Debenham from Half Moon Crater on Hut Point Peninsula.

The trachytes of the cones, the limburgitic basalts, and, possibly, the kenytes carry each their own suite of coarse-grained inclusions. Fragmental rocks, tuffs, and agglomerates are to be found associated with the kenytes, and with the basalts at many localities. Some evidence as to the relative ages of the different rock-types may emerge from the study of the petrography of these inclusions.

The field evidence as to the relative ages of the different kinds of lava shows that in Hut Point Peninsula and on the mainland opposite Ross Island the basalts are the most recent lavas, but that on Mount Erebus the most recent lavas are the kenytes. The basalts with tabular feldspars and the phonolitic trachytes on the mountain seem to belong to the earlier phases of its vulcanicity.

II. PHONOLITIC TRACHYTES AND TRACHYTOID PHONOLITES

Trachytic rocks in the Ross Archipelago are represented by several outcrops and a few erratics of grey to dark grey rocks, which appear on the results of chemical analysis and petrographical examination to range from trachytoid phonolites to phonolitic trachytes.

They have already been described both by G. T. Prior* and by H. I. Jensen† from material collected by the National Antarctic Expedition of 1901–4 and the British Antarctic Expedition 1907–9. Three types of these rocks have been analysed, and the other specimens collected can be referred to one or other of these types or can be described as variants or transitional from one to another.

The rocks chosen as types are:

(1) The dark greyish-olive 'trachyte' of the parasitic cone called Mount Cis, on Mount Erebus, with few feldspar phenocrysts and occasional small olivines.

(2) The deep olive-grey 'trachyte' of Cape Crozier, Mount Terror, with abundant microphenocrysts of feldspar, referred to as the Mount Terror type.

(3) The hornblende-bearing 'trachyte' of Observation Hill, Hut Point, described by Prior in 1907 (op. cit. p. 117), referred to as the Observation Hill type.

As to the classification of each of these types opinions may differ. The choice seems to lie between 'phonolitic trachyte' and 'trachytoid phonolite', and the distinguishing criterion is the content of feldspathoids or the proportion of feldspathoids among the light mineral constituents of each type.

The expression 'phonolitic trachyte' was first used by Rosenbusch‡ in 1908. He explained that the adjective 'phonolitic' was not to be taken to imply a marked fall in silica percentage as compared with normal trachytes, but rather the occurrence in the rock of constituents characteristic of the phonolites and a complete absence of free silica. Chemically they are slightly undersaturated trachytes.

The name 'trachytoid phonolite' was given by Rosenbusch in 1887 to nepheline-poor phonolites, and the name appears to be synonymous with the 'trachyphonolite' of Boricky, 1875, and the later 'trachytic phonolite' of Hibsch, 1902.

Tröger has chosen Rosenbusch's name in preference to Boricky's, and although the latter has priority, one may accept his decision for the present.

There are, of course, rocks representing every stage in the passage from phonolitic trachytes to trachytoid phonolites, and in practice there have been wide differences of opinion as to how the limit should be defined. For some petrographers the distinction is made on the hand-specimen between rocks with the characteristic rough feel of typical trachytes and those with the smooth fracture and compact groundmass of typical phonolites. Experience shows that rocks with external characters of the typical trachytes may carry quite considerable proportions of nepheline and the 'field' distinction does not correspond to a mineralogical difference. For those of us who look for some quantitative mineralogical distinction there is a wide choice depending on the particular system one wishes to adopt.

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* Prior (G. T.), Nat. Ant. Exp., 1901–1904, Nat. Hist., vol. 1, Geology, 1907, pp. 113–19.

† Jensen (H. I.), Brit. Ant. Exp., 1907–9, Geology, vol. 2, 1916, pp. 94–103.

‡ Rosenbusch, H., Mikroskopische Physiographie, vol. 2, 1908, p. 923.

On Johannsen's system, based on the modal composition, the upper limit for phonolitic trachytes is at nepheline 5 per cent by volume of the feldspars and feldspathoids. P. Niggli would modify this to 12·75 per cent to conform more nearly to normative weight per cent used in the C.I.P.W. system (and in the system of Lacroix). W. E. Tröger* sets the limit at feldspathoids 10 per cent by weight of the light minerals.

Whichever of these quantitative limits be adopted, it is found that many of the rocks with all the external characters of trachyte in the field come well within the range of the phonolites as defined in terms of the component minerals or normative minerals and, unless a drastic change in classification is to be made, it is as trachytoid phonolites that they should be described.

Two important types of lavas from the Ross Archipelago described by Prior as 'trachytes' fall within the field of the trachytoid phonolites. They are the Mount Terror and the Observation Hill types (2 and 3 above). The remaining type, the Mount Cis type, is a phonolitic trachyte.

Phonolitic Trachyte (Mount Cis type)

Phonolitic trachyte, Jensen, 1916, p. 94.
Trachyphonolite, Jensen, 1916, p. 98.

The trachyte that forms the parasitic cone of Mount Cis on Erebus is a somewhat vesicular, aphanitic rock, greyish-olive in colour, with rare insets of feldspar (up to 8 mm. in length) and showing a sheen from parallel feldspar laths on some broken surfaces. Under the microscope one notes in addition to the occasional feldspar insets a few microphenocrysts of green pyroxene, olivine, and opaque 'ore', but these are all scarce, and the main mass of the rock consists of slender feldspar laths with well-developed trachytic structure and dark interstitial groundmass.

In very thin sections the dark interstitial material can be resolved and is then seen to consist of a very pale green to colourless pyroxene with very low extinction angles and a brown amphibole, like catophorite, and grains of opaque 'ore'. Very small short rods of opaque 'ore' (magnetite ?) in parallel position over small areas are noticeable under high magnification. There are some small colourless isotropic areas.

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* Tröger (W. E.), Spezielle Petrographie der Eruptivgesteine. Berlin, 1935, p. 339.

These trachytes have been fully described by Jensen (op. cit. pp. 94–100). He found the mineral composition almost the same in all specimens examined and gave the modal composition as follows: 'Felspar forms from 60 per cent. to 75 per cent. of the mass, and aegirine-augite from 10 per cent. to 25 per cent.

'The balance is made up of olivine, magnetite, leucite, sodalite, interstitial nepheline (?), analcite, cossyrite, riebeckite, and various ferritic decomposition products, some or all of which occur together to the extent of from 5 per cent. to 10 per cent. in all specimens. Of these magnetite usually forms up to 5 per cent., olivine up to 2 per cent. A cossyrite-like hornblende occasionally replaces aegirine so as to form upwards of 5 per cent. Apatite is occasionally sparingly represented in long needles. Felspathoids range from 1 per cent. to 10 per cent. in amount' (op. cit. p. 96).

The feldspars of the groundmass were identified by Jensen as anorthoclase. He based this on the following properties: refractive index slightly below Canada balsam, twinning mainly Carlsbad, but 'shadowy extinction of the moirée type indicated the presence of ultramicroscopic twinning in some crystals, the sanidine cross cracking or parting was fairly common, cleavage almost rectangular, and extinction angles varied from 0° to 8° with the length of the laths'. He does not record any insets of feldspar in any of his descriptions of specimens from Mount Cis.

The pyroxenes he finds consist chiefly of aegirine-augite of a greenish-yellow colour with extinction varying between 20° and 35°. In some specimens true aegirine, and in others colourless diopside, accompany the aegirine-augite.

The amphiboles are cossyrite-like. 'They may be scattered about in grains or form ophitic aggregates of a deep coffee-brown colour, pleochroic from olive-brown to deep brown, opaque in sections across the length. In some slides these amphiboles show a deep purplish-blue absorption colour on rotating the stage, indicating affinities with riebeckite or some species of kataphorite. . . . Riebeckite occurs only very rarely. . . . Arfvedsonite is occasionally secondary after aegirine-augite. . . . Olivine occurs only sparingly, and only as phenocrysts, . . .'

Magnetite is described as a common accessory, and Jensen adds: 'It is not improbable that in some of the rocks the cubic and octahedral black isotropic grains provisionally identified as magnetite may be a black variety of perovskite, knopite, or geikielite'. Of the feldspathoids he says: 'Usually they are interstitial. . . . In addition to filling smaller interstices these minerals may form larger patches into which felspar needles penetrate. The commonest felspathoids are sodalite and analcite' (op. cit. p. 97).

The sample of this 'trachyte' analysed by Hogarth for Jensen was from J13, a description of which is given by Jensen (pp. 99–100). A section of a duplicate specimen of the analysed rock in the British Museum collection shows a groundmass of slender laths of feldspar, identified by Jensen as anorthoclase, with interstitial aegirine-augite, and soda-amphiboles, and some colourless isotropic material (probably sodalite). The section of the British Museum specimen [BM. 1911, 135, 13] shows also very small insets of olivine, a pyroxene (colourless in thin section) and magnetite. In the groundmass the feldspars are very closely packed and the interstitial areas are very narrow and generally triangular in shape. A brownish amphibole, like catophorite, is present as well as the arfvedsonitic amphibole noted by Jensen, also a pale green pyroxene. There are minute microphenocrysts of colourless olivine and scattered magnetites (Pl. 3, Fig. 1). A microchemical test proved the presence of feldspathoids in the groundmass. A hand-specimen shows occasional small, tabular feldspar insets.

Jensen described another specimen [J1] which, he notes, the analysed specimen resembled. This had insets of green aegirine-augite and small nephelines most of which, however, were represented by pseudomorphs. In the groundmass he recorded: 'felspar microlites with the properties of anorthoclase, and aegirite or acmite . . . in hypidiomorphic prisms and allotriomorphic aggregates behaving ophitically to felspar'. In addition he noted magnetite as an abundant minor constituent, a 'deep brownish-green arfvedsonite amphibole enveloping deep blue riebeckite grains', and a brown cossyrite-like hornblende present in minute amount (op. cit. p. 99 and pl. 1, figs. 1 and 2).

Another trachyte from Mount Cis [J32], also briefly described by Jensen (op. cit. p. 100], is somewhat finer grained and vesicular. Under the microscope it shows a few small phenocrysts of 'anorthoclase' (5 mm.) and microphenocrysts of a slightly yellow olivine (up to 0·25 mm.) with rarer, very pale greenish aegirine-augite and small magnetites. The groundmass is holocrystalline and consists mainly of slender laths of feldspar, often in divergent radial groups with abundant very small prisms and flakes of a green pyroxene with very low extinction angles (probably aegirine), unidentified soda-amphiboles, opaque 'ore', and many patches of colourless material. The amphibole resembles catophorite.

Jensen detected: 'a little nepheline and minute insterstitial crystals' by staining methods. He thought the colourless patches were sodalite but they seem often to be birefringent and have too high a refractive index; it is more probable that they are nepheline. Conspicuous features in the thin section of the British Museum specimen of this rock [1911, 135 (32)] are parallel rods of magnetite (?) traversing the groundmass minerals in certain areas, and many very small colourless cubes, about 0·003 mm. across, in the colourless base. These have low refractive index and are probably sodalite.

One of the specimens from Mount Cis collected by the British Antarctic Expedition and presented to the British Museum [BM. 1911, 135 (27)] is of interest as the colourless interstitial material of the groundmass appears to be glass. It is crowded with minute crystallites, which are probably pyroxene, and magnetite. Amphiboles were not detected. The abundant feldspar laths of this rock show the same strong trachytic arrangement as the other Mount Cis specimens. There are occasional microphenocrysts of aegirine-augite, and apatite and olivine are rather rare accessories in addition to the more abundant opaque 'ore' (magnetite ?).

Two analyses have been made of this trachyte: one, by Hogarth, published in column

A, table I, of Jensen's memoir (op. cit. p. 98) quoted here in column 2, Table I*a*; the other, made on a duplicate specimen of the one analysed by Hogarth, was made by Mr. D. I. Bothwell, B.Sc., under Dr. M. H. Hey's direction in the Department of Mineralogy, British Museum (Natural History). The two analyses differ in the relative proportions of ferrous and ferric iron, and the K_2O content is slightly higher in the new analysis. Also Hogarth's analysis shows an unusually high P_2O_5 content for a rock of this kind. These differences lead to considerable differences in the norms. Jensen's norm shows hypersthene and free silica, whereas that derived from the new analysis is the norm of a slightly undersaturated rock with small contents of normative nepheline and olivine. The differences might be due to contamination of Hogarth's sample with very small relics of sedimentary xenoliths which are very frequent in this rock. Mr Bothwell took pains to pick material free of xenoliths before finely grinding the sample for analysis. The norm calculated from the new analysis is in fair agreement with the modal mineral composition of the rock and the name 'phonolitic trachyte' seems quite justified.

Jensen considered (op. cit. p. 99) that: 'The Mount Cis trachyte, J. 13, is in mineral composition and microscopic structure similar to the phonolitic trachytes from Cape Adare and Cape Crozier, . . .'. The rock from Cape Crozier referred to was described as phonolitic trachyte by G. T. Prior (op. cit. 1907, p. 114). Its analysis shows that it contains a higher percentage of normative nepheline than the Mount Cis trachyte, and accordingly it is here regarded as a distinct type and classified as a trachytoid phonolite (p. 27).

Other rocks with which Jensen compared the Mount Cis 'trachyte' are the phonolitic trachytes of Dunedin, New Zealand, described by Marshall,* and the trachyandesites of the Warrumbungle Mountains. These were described by Jensen.† Most of them seemed to be 'free from felspathoid mineral, but some contain a little interstitial nepheline' and they were classed together as 'trachyandesites and phonolitic trachytes' (op. cit. p. 602).

The Mount Cis 'trachyte' contains numerous inclusions of sanidinite, microsanidinite, and also xenoliths derived from the sedimentary rocks through which the volcanic rocks have burst. These were referred to by Edgeworth David and Priestley ‡ and were described in detail by J. Allan Thomson.§ The last-named author distinguished in addition to sanidinites and microsanidinites, quartz-pyroxene inclusions which he regarded as derived from impure sandstones, and pyroxene-plagioclase inclusions that he thought were derived from dolerites. The inference drawn both by David and Priestley and by Thomson was that both these types were relics of fragments torn from the Beacon Sandstone Formation and from its extensive sills of quartz-dolerite.

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* Marshall (P.), The geology of Dunedin (New Zealand). Quart. Journ. Geol. Soc., 1906, vol. 62, p. 403.

† Jensen (H. I.), Proc. Linn. Soc. New South Wales, 1907, vol. 32, p. 616.

‡ David (T. W. Edgeworth), and Priestley (R. E.), Brit. Ant. Exp. 1907–9, Geology, vol. 1, 1914, pp. 221 and 307.

§ Thomson (J. Allan), Brit. Ant. Exp. 1907–9, Geology, vol. 2, 1916, pp. 131–48.

Both Debenham and Priestley in 1911 made extensive collections of these inclusions in the lava of Mount Cis and obtained many examples of all the kinds described by J. Allan Thomson. The inclusions in Debenham's specimen [D19R] are fine-grained, grey microsanidinites. One has a fine-grained granulitic texture (0·05 mm.); others show the orthophyric texture of small, quadratic feldspars as described and figured by Thomson (op. cit. p. 136), and one section shows very well a border of larger (2 mm.) crystals of feldspar growing out into the host rock. An example of this was described by Thomson also (p. 139). It appears as if the feldspars of the xenolith had recommenced growth, drawing their material from the still molten lava and growing out into it.

Debenham also collected many examples of inclusions that have all the appearance of xenoliths derived from sedimentary rocks. The fine-grained, central portion of one of these inclusions was found to consist mainly of rounded quartz grains in a matrix partly isotropic and partly birefringent. The outer part of the inclusion, where it adjoins the lava, is cinnamon-buff in colour and is vesicular. This part consists of glass with a few residual grains of quartz. The glass has refractive index less than 1·499 and contains numerous crystallites of feldspar, olivine, and pyroxene, the last less abundant than the others.

These are the inclusions described by Thomson as 'slaggy'. He considered they were derived from impure sandstones and there seems to be no doubt of that. Among the series collected by Debenham and Priestley are several specimens in which the xenoliths resemble various varieties of the cream-coloured and grey Beacon Sandstones and it seems certain that the Beacon Sandstone Formation provided the material for these xenoliths. The central portions are fritted and fused sandstone and are recognizable as such but their outer zones have received a considerable contribution from enclosing lava and the smaller xenoliths are entirely transformed leaving only relics of quartz grains to show their origin.

A very fine-grained inclusion [D19Rb], pinkish buff with pale greenish patches, carries in these patches granular pale green pyroxene, $c: \gamma = 48^\circ$, and refractive index greater than 1·686. The colourless minerals are for the most part feldspars as very small allotriomorphic grains or small quadrate crystals. It seems that some of the feldspar is plagioclase though only very rarely do grains show albite or pericline twinning. Most of the colourless mineral has refractive index around 1·54 but on account of the extremely fine grain definite identifications were not made. There is some interstitial glass of low index and faintly tinged pinkish buff. This inclusion may represent one of the more calcareous, impure bands in the Beacon Sandstone. No other inclusions of the kind have been sectioned. It was thought it would prove to be of the same kind as the plagioclase-pyroxene inclusions in the trachyte of Mount Cis described by J. Allan Thomson (op. cit. p. 143 and pl. 3, figs. 1 and 2) and interpreted by him as fragments of dolerites probably derived from the sills in the Beacon Sandstone, but the habit of the feldspars seems to be quite different.

Trachytoid Phonolite (Mount Terror type)

Phonolitic Trachyte, Prior, 1907, p. 114.

Rocks which can all be referred to one type of trachytoid phonolite have been found at the SW. foot of Mount Terror (Cape Crozier), at Cape Bird, in the Dellbridge Islands off the SW. coast of Ross Island, and on Brown Island, and Black Island. Prior described 'trachytes' collected by Ferrar from each of these localities and many more specimens of the type were collected by members of the Terra Nova Expedition on all of the islands of the Dellbridge group.

In hand-specimens these rocks are compact and deep olive-grey in colour. They carry small insets of feldspar in an aphanitic groundmass. Fractured surfaces show reflections from broad laths of feldspar.

Prior (op. cit. p. 114) has given a general description of rocks from the localities mentioned above which can all be referred to the type rock analysed by him from Cape Crozier. He writes (p. 115): 'Closely related to the preceding [i.e. the type rock (188)], but of a more definite trachytic type, are other ash-gray rocks, which show under the microscope small, sharply defined rectangular phenocrysts of anorthoclase in a groundmass consisting of a trachytic mesh of felspar-laths, with interstitial dull-green aegirine-augite and a little magnetite (see Plate VIII, Fig. 4). The felspar-phenocrysts show the minute twin-striations characteristic of anorthoclase, and similar striations can also be detected in some of the larger felspar-laths of the base. The aegirine-augite is in small, prismatic crystals, and shows pleochroism from brownish yellow to dull-green'.

Specimen 188 from the Discovery collection, collected from the top of a 900-foot knoll at Cape Crozier, Mount Terror, was analysed by G. T. Prior (op. cit. p. 114). The results are quoted in column 3, Table I*a*. The hand-specimen is compact, deep olive-grey, and shows small insets of feldspar. It contains an angular fragment of a hornblende-pyroxene-feldspar rock which Prior briefly described.

The thin section shows some colourless material in the interstices between the feldspars, and the microphenocrysts are not always sharply defined and rectangular. The aegirine-augite in the groundmass often forms small plates, some so thin as to be practically colourless. These microphenocrysts have the pleochroism described by Prior and give extinction angles $c:\gamma$ up to 62°. Very small crystals of magnetite surrounded by brown alteration products, and a little secondary biotite are fairly abundant. There are occasional small insets of hornblende completely resorbed and replaced by magnetite. Minute sodalite crystals are visible under high magnification within the feldspar and in interstitial patches. A microchemical test showed the presence of soda-feldspathoids in the base.

The norm calculated from Prior's analysis (Table I*b*, column 3) shows 18·74% *ne*, rather more than one-fifth of the light constituents. It would be difficult, if not impossible, to make a close estimate of the amount of feldspathoids present in the mode but they probably account for at least a tenth, and perhaps an eighth, of the light minerals. This would justify the classification of the Mount Terror 'trachyte' as a trachytoid phonolite.

In Professor Debenham's collection this Mount Terror type is very well represented by numerous fresh specimens from Inaccessible Island, where Ferrar had also collected this type [804]. These rocks are a little richer in aegirine-augite ($c:\gamma$ up to 54°) and they contain also scattered grains of yellowish olivine [D1I, D17I, D24I]. The feldspars show simple Carlsbad twins (Pl. 3, Fig. 6). The hand-specimens are dark greyish olive with numerous small, white insets of feldspar in an aphanitic groundmass, or aphyric and deep olive-grey with the sheen on fractures due to the parallel feldspar laths.

Jensen described several 'phonolitic trachytes' from Inaccessible Island (op. cit. p. 103). His specimen [J16 = BM. 1911, 135 (16)] is similar to the rocks just described. Two others are referred to below.

Other examples of the same type in Debenham's collection are: D24E(*b*) from the west side of Tent Island, a very well crystallized example with long feldspar laths and granular pyroxenes; and a finer grained type containing a few resorbed hornblendes. This latter specimen [D52E] was one of many collected on Tent Island by C. S. Wright.

In passing it may be noted that 'trachytes' similar to those described above were collected at Cape Bird by Sir Edgeworth David and R. E. Priestley on the British Antarctic Expedition 1907–9 [P314 and P336]. These rocks carry a few microphenocrysts of resorbed hornblende and one of them [P336] has small insets of a fresh, green aegirine-augite. These were not described in H. I. Jensen's report.

Glassy and partly glassy types of phonolitic trachytes probably corresponding to the Mount Terror type are represented from Inaccessible Island by several specimens: D2I in Debenham's collection and 802 in Ferrar's collection. In some of these [802, D2I] the glass is brown and the hand-specimens are deep brownish drab. A fresher specimen, iron-grey in colour, is one described by Jensen [J15] (op. cit. p. 103).

The feldspars are simple twins of orthoclase or anorthoclase, and they average about 0·2 mm. in length, and do not exceed 0·35 mm. in the specimens measured. The groundmass is glassy, mainly turbid, with clearer patches, and contains minute brown hornblendes and magnetite.

A smoke-grey lava from the scree at the foot of the eastern cliff of Inaccessible Island [D7I] is similar to two specimens collected by Ferrar at the north-west end of the Island [807, 803]. These are poorer in dark minerals than the greyish olive, holocrystalline rocks described above, but they seem to be nothing other than the light-coloured, altered or weathered representatives of the partly glassy types just described. They contain a few well-developed, rectangular phenocrysts of anorthoclase, and for the rest consist of abundant laths of feldspar, with a few yellow, altered pyroxenes and grains of magnetite in an isotropic base. The base is partly turbid but there are abundant clear patches. The feldspars have one refractive index higher than Canada balsam and the altered pyroxenes gave extinctions, $c:\alpha$ up to 18°, but few measurements could be obtained.

A similar specimen, but darker in colour, is described by Jensen from Inaccessible Island under the name phonolitic trachyte [J21] (op. cit. p. 102). The colour of the hand-specimen is hair-brown to greyish olive and the rock seems to represent an altered facies of one of the varieties of the type rather richer in pyroxene. The dark minerals are mostly altered to opaque material but the bright yellow altered pyroxenes, as seen in D7I, are still abundant.

Specimens referable to the Mount Terror type noted by Prior among those collected by H. T. Ferrar on Black Island are the 'trachytes' referred to below in connexion with the discussions of the relationship between greyish and yellowish trachytes and the state of alteration of the pyroxene microliths.

These 'trachytes' have seriate porphyritic texture. The greyish olive rock [610] in thin section shows microphenocrysts of lath-shaped anorthoclase quite abundant, with microphenocrysts of a dark green aegirine (or aegirine-augite) in a groundmass of feldspar, sodalite, and minute prisms of aegirine. The sodalite occurs in grains and minute crystals enclosed by feldspar. The lighter, pale vinaceous fawn rock associated with this [609] is identical in character except that the dark green pyroxene is replaced by a deep yellow, weakly pleochroic mineral of the same form as the pyroxene.

Related to the Mount Terror type but containing, in addition to microphenocrysts of pyroxene, a few small olivines and brown hornblendes (usually resorbed), are several of the rocks from Big Razorback Island in the Dellbridge group.

D29E from the west base of Big Razorback, below The Turret, and D31E from the east of Big Razorback 'in the middle', are very fine-grained with much feldspar in the groundmass and fewer microphenocrysts, though these include occasional fresh brown hornblende and pyroxene as well as anorthoclase. Prior described a similar rock [473] collected by Ferrar from Little Razorback (op. cit. p. 114). These rocks are light olive-grey in colour, aphanitic and compact.

The specimen from the east end of Big Razorback [D28E] is iron-grey, nearly black, and shows thick platy jointing. It has a higher proportion of dark minerals than some of the 'trachytes' of Inaccessible Island, and in addition to pyroxene in the groundmass there are numerous very small brown crystals which appear to be altered olivine. The feldspar insets appear to be anorthoclase, but some are undoubtedly plagioclase (oligoclase-andesine near An_{30}). A rather similar, dark grey trachytic lava is from an outcrop at the base of Tent Island on the west side, beside a small delta [D21E].

What may be a glassy facies of these rocks [D30E] from near the summit at the NE. end of Big Razorback is olivaceous black and vesicular in hand-specimen. This has as microphenocrysts, however, many small ilmenites or magnetites, a few pyroxenes, and many small feldspars some of which show good albite twinning and have a refractive index greater than Canada balsam; so the rock may be a rather more basic type.

Another variant of the Mount Terror type is the 'trachyte' from the summit of Abbott's Peak [D9O and D19O]. This is pale olive-grey rock with abundant small insets of feldspar, pyroxene, and some of brown hornblende (partly resorbed) and pale yellowish olivine.

The olivines are almost colourless; the pyroxene with extinction angle $c\colon \gamma = 47°$; shows weak pleochroism; β' pale olive-buff; $\alpha' = \gamma' =$ light mineral-grey to yellowish glaucous. Some of the feldspar phenocrysts are anorthoclase with refractive index less than balsam, but many show well-defined albite lamellae and have higher refractive indices and are strongly zoned. They are probably anorthoclase (potash-oligoclase). Apatite occurs as an accessory in the form of needles. The groundmass is very fine-grained and consists of feldspar laths and plates with minute prisms of nearly colourless pyroxene (perhaps also olivine) and grains of magnetite with flakes of secondary biotite (Pl. 3, Fig. 5). Some 'sodalite' is identifiable and there may be insterstitial nepheline. The feldspar phenocrysts often contain inclusions of pyroxene and one contains a prism of the brown hornblende and has preserved it unresorbed.

Such rocks may be transitional between the trachytoid phonolites and the kenytes as suggested by Prior (op. cit. 1907, p. 114).

Trachytoid Phonolite (Observation Hill type)

Hornblende-trachyte, cf. '*tephritic trachyte*,' Prior, 1907, p. 117.
Kaersuetite (?), *Aegirine-augite Trachyte*, Jensen, 1916, p. 101.

These are the rocks which Prior described (op. cit. pp. 117–19) as composing the whole of Observation Hill. They were also described from the same locality (op. cit. p. 101) by Jensen. Professor Debenham collected many specimens and mapped the outcrops on a plane-table chart of Hut Point Peninsula.

In hand-specimen the rocks range in colour from light neutral grey to deep neutral grey, with occasional thin bands and some irregular included patches of olive-grey and olive-buff colour. They often have conspicuous platy structure and some specimens show abundant lapilli-like inclusions. Ferrar* describes those on the higher part of Observation Hill [278–280] as yellow, locally streaked with grey ribbon-like bands [288] which follow the flow-structure, and he adds: 'On the southern side of the summit the darker rock begins to preponderate, and at a point some 30 yards away from the top, and 50 feet below it, the yellow rock gives place to a dark-grey hornblende-trachyte (290). Below this rock comes another dark-grey hornblende-trachyte with spheroidal structure (655).'

The specimen analysed by G. T. Prior, chosen for its fresh condition, was No. 277, recorded by H. T. Ferrar as a dike-rock traceable up the higher part of the hill. Debenham's collection includes a specimen [217] from 'a ridge running up the west side of Observation Hill'. This is identical in all its characters with Ferrar's dike-rock [277] and Prior has described another exactly similar rock [290] from the southern side of the summit (see above).

The analysed rock is iron-grey in colour in the hand-specimen and shows a sheen from parallel feldspar laths on some fractured surfaces. It appears at first sight to be compact but under the microscope it can be seen to be vesicular, the vesicles being very small.

Prior, describing these rocks (op. cit. p. 117), writes: 'These trachytes show no phenocrysts of felspar, augite or olivine. Under the microscope are seen small prismatic crystals of basaltic hornblende (or of black magnetite-pseudomorphs after it) in a trachytic mesh of minute felspar-laths, showing generally well-marked flow-structure, with thickly disseminated grains of magnetite and small needles of pale dull-green augite' (see Pl. 3, Fig. 2).

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* Ferrar (H. T.). Nat. Ant. Exp. 1901–1904, Nat. Hist., vol. 1, Geology, 1907, p. 13.

Prior described and figured the 'lapilli-like inclusions' (op. cit. p. 118 and fig. 66) and found them to consist of 'a dense mesh of interlacing prisms of basaltic hornblende, similar to that in the trachyte, with magnetite-grains and only a little interstitial felspar'. He also describes two glassy varieties of the rock in one of which [442] he finds 'small dendritic patches . . . of magnetite (possibly altered riebeckite or other soda-hornblende)' (op. cit. p. 118 and fig. 65); in the other [264] 'minute colourless circular or roughly six-sided and eight-sided isotropic crystals' (op. cit. p. 117 and fig. 64). These he finds have a refractive index less than Canada balsam and he refers them to leucite. The crystals average about 0·015 mm. in diameter (Pl. 3, Fig. 4).

Minute isotropic crystals which seem to be similar to these but average about 0·04 mm. in diameter and all less well-formed are abundant in a glassy facies of the trachytes collected by Debenham from Observation Hill [D2H]. The refractive index seems to be less than that of the glassy base but the edges of the crystals are fuzzy with minute dark crystallites and definite observations on the refractive index are difficult to obtain. In the slide described by Prior the edges are clear and sharp and the refractive index can be seen to be less than that of the glass and, I think, also less than Canada balsam. One is, however, inclined to refer them to sodalite rather than to leucite but there seems to be no means of deciding the matter on material available.*

The hornblende in the 'trachyte' was referred by Prior to barkevikite. Jensen (p. 101) referred it to kaersutite and regarded it as of the same kind as the hornblendes occurring in clusters in the rock. These hornblendic inclusions were figured and described by Prior (op. cit. p. 118), who gave the characters of the hornblende as: pleochroism; α yellow, β and γ deep reddish brown: extinction straight; elongation positive.

The present author's own observations on the amphibole in Prior's specimen [264] and Debenham's 2H are: pleochroism; α amber-yellow to olive-ochre, β Dresden brown to nearly black, γ cinnamon-brown to sepia; absorption, $\beta=\gamma>\alpha$. The extinction angle measured is $5\frac{1}{2}°$.

It would be impossible to discriminate between barkevikite and kaersutite on the basis of these data and it has so far proved impossible to measure 2V on the material available.

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* The crystals described by Prior have very definite outlines, much more definite than is usually seen for either leucite or sodalite in such conditions. They are concentrated in one small patch in the section. They may well be some rather rare accessory mineral. In the absence of specimens other than the small one available one must reluctantly leave them unidentified.

In an etched slide of 264 they do not take a stain but that may be because they are so small that those that have survived the sectioning process are protected from the acid by the rock-glass. They lie within the thickness of the section.

The feldspars in the analysed rock [277] and in Debenham's specimen appear to be anorthoclase. They occur as laths with simple Carlsbad twinning. Extinctions are indefinite. Some laths give refractive index, for vibrations along the length, less than balsam; those at right angles slightly greater. Prior found in the glassy variety [204] that the platy feldspars gave refractive index less than balsam (corresponding to α and β'), and the lath-shaped feldspars slightly higher (corresponding to β and γ). He came to the conclusion that 'most of the felspar is probably anorthoclase'.

In a glassy facies in Debenham's collection [D2H] there are microphenocrysts of feldspar which show twinning on the albite law giving symmetrical extinction angles up to 21°, corresponding to andesine near An_{40}. The same rock has feldspar laths in the groundmass giving very low or straight extinction with refractive indices very near and slightly greater than balsam. These are probably anorthoclase.

Debenham's collection contains many specimens of the trachytes, which differ from Prior's analysed type in containing very abundant microliths of feldspar and in showing a well-developed trachytic texture. The feldspars indeed make up most of the rock. There are also abundant small brown hornblendes and a few microphenocrysts of plagioclase [D2H]. The groundmass is a colourless glass crowded with microliths of colourless pyroxene and minute grains of magnetite (Pl. 3, Fig. 3). In some specimens the hornblendes have black edges marking the commencement of resorption. It is one example of this type with a clear, colourless glassy groundmass which contains the minute isotropic crystals mentioned above. In hand-specimen these rocks are light neutral grey to deep neutral grey in colour and are finer grained than Prior's analysed type.

A trachyte of somewhat different type is D3H from the crest of Crater Heights. One may compare with it also a specimen [218] from 'true summit of Observation Hill' and, probably, [219] S. summit, and [220] Spot D, Crater Heights.

Sections of D3H cut perpendicular to the platy jointing show strong trachytic texture. The rock consists of closely packed laths of feldspar (anorthoclase) with abundant pale yellow ragged prisms of a pyroxene, colourless crystallites of a pyroxene, and grains of magnetite in a colourless glassy base. Some minute sodalites occur in the glassy base. Throughout the rock are resorbed phenocrysts of hornblende, and some of these are so small and numerous as to cease to rank as phenocrysts and actually form part of the groundmass.

This is also the kind described by Jensen as 'Kaersuetite (?), Aegirine-augite Trachyte', [J3 (1913) = BM. 1911, 135(3)] and figured in his report on the petrology of the alkaline rocks of Mount Erebus (op. cit. p. 101 and pl. 1, figs. 3 and 4).

These rocks are olive-grey to olive-buff in colour and have thin platy jointing. Ferrar describes similar rocks also from Observation Hill. He found yellow hornblende-trachytes [278, 279, 280] forming the higher part of the hill and thought these were younger than 'the dark-grey hornblende-trachyte [273, 281] with abundant lapilli-like inclusions'. At the top of the hill he found a yellow trachyte locally streaked with grey ribbon-like bands. The pale olive-grey rock [281] corresponds to the olive-grey 'trachytes' in Debenham's collection [D3H] and the yellow 'trachytes' [278–280] to the olive-buff rocks from the true summit [218] and from Point D, Crater Heights [220].

Prior considered that 'the yellow rocks from the top of the hill appear to be only weathered gray rocks'. He writes (op. cit. p. 117): 'In specimens showing alternating bands of gray and yellow . . . these bands show under the microscope a precisely similar and continuous mesh of felspar-laths, and only differ in the yellow bands containing plentiful yellow grains of epidote in place of the minute magnetite-grains and small dull-green augites of the gray bands'.

My own observations on Debenham's specimens are that the olive-grey rocks [e.g. D3H, 218] carry a pale green pyroxene with $c : \alpha$ up to 22°, but the olive-buff specimens show a pale yellow mineral in place of the pyroxene.* So far as I can ascertain this yellow mineral is not epidote but altered pyroxene (or perhaps pseudomorphs of pyroxene by epidote). Satisfactory measurements are difficult to obtain on such small crystals. With this reservation Prior's contention that the olive-buff rocks are the weathered (or altered) olive-grey rocks seems to be supported by the material collected on the Terra Nova Expedition. Moreover, similar relationships appear to hold between a deep greyish olive 'phonolitic trachyte' [610] and a pale vinaceous fawn trachyte of similar texture [609], collected by Ferrar on Black Island. Yet another example of a related pair of lighter and darker 'trachytes' are the specimens of D7I from Inaccessible Island. Both these and the 'trachytes' from Black Island belong to the Mount Terror type described above.

The only other hornblende-bearing 'trachytes' found in the Ross Archipelago, apart from 'trachytes' of the Mount Terror type, with occasional small hornblende insets, are represented by two specimens from Cape Bird [J18 = BM. 1911, 135(18) and P315 = BM. 1911, 135(54)]. The former was described by Jensen as 'altered Phyro-hornblende Trachyte'. An analysis was made by Mr Burrows and A. B. Walkom which is quoted in column 7, Table I*a*, and Jensen has given a figure of a thin section (op. cit. pl. 3, fig. 5). These are olive-grey rocks with numerous small black resorbed hornblende insets. Under the microscope the completely resorbed hornblendes are seen to be very abundant and there are abundant granules of green aegirine-augite in the groundmass, but otherwise they are similar to the Observation Hill type described above. The norm calculated from the analysis shows: olivine 4·41 and slightly higher *an* and *di* and lower normative nepheline than in the norm of the Observation Hill 'trachyte', but the two analyses do not differ very much from one another. Prior's analysis is quoted in column 6, Table Ia.

It may be noted that the norms calculated from the chemical analyses of these rocks, the Observation Hill type and the one from Cape Bird, show 21·6 and 15·3 per cent nepheline respectively, representing 25 and 20 per cent of the light minerals. The modal nepheline has not been measured in these rocks but it is unlikely that the total feldspathoids would fall to as little as 12·75 or even 10 per cent of the light minerals of the rocks. One must therefore rank them with the trachytoid phonolites rather than with the trachytes.

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* It is worth noting also that it is the olive-buff specimen that shows best the abundant minute particles of sodalite in the groundmass.

It will be noted also that in the C.I.P.W. classification rock analyses that fall in the same sub-rang as the Mount Terror type, I(II).6.1.″4, include many phonolites and tinguaites among which are some from such localities as Kerguelen Island and New South Wales* and the Canary Islands. Also, in the corresponding sub-rang of Class II, in which the analysis of the Observation Hill type just falls, (I)II.6.1.″4, one finds not only phonolites and tinguaites from Kerguelen and New South Wales and the Canary Islands, but also a whole series of analyses of kenytes from Mount Kenya and 'Rhombenporphyr' and trachydolerites from Kilimanjaro described by L. Finckh (1906) and B. Mauritz (1908).†

A comparison of volcanic rocks collected on Kerguelen by the Challenger Expedition and described by the Abbé A. Renard‡ is of some interest as the collection contains 'augitic trachytes' from Greenland Harbour and from Coronet Hill which are sufficiently like some of the trachytoid phonolites of Observation Hill type (e.g. D3H) to suggest that there may be close similarities between the more acid lavas of Kerguelen and those here described.

Some specimens collected in Cumberland Bay, Kerguelen, by (then) Surgeon Robert M'Cormick, R.N., during the Antarctic Expedition under Captain Sir James Clark Ross in 1840 [B.M. 75115, 75125, 75128] also show similarities to the Observation Hill type.

There are some types of phonolitic trachyte described by Prior and by Jensen which were not represented in the Terra Nova collections. It may be convenient to complete the record by recapitulating here their characters.

613. Minna Bluff. 'A dark greenish-brown compact rock showing no phenocrysts' (Prior, op. cit. p. 116). The colourless minerals of the groundmass are feldspar (orthoclase or anorthoclase) and abundant sodalite as small grains enclosed in feldspar. This type of groundmass with rather larger feldspars as microphenocrysts and dark green pyroxenes (aegirine) is found also in 610 from the SE. end of Black Island (see also p. 35). Prior's description of 613 is as follows:

'Under the microscope are seen feathery flakes of pale-green aegirine-augite, and ragged tufts of cossyrite and of a brown altered mineral (probably another soda-hornblende or pyroxene). These are thickly and uniformly distributed in a rather unindividualised base, showing indistinct felspar-laths and a few magnetite-grains; nepheline is probably present in the base, but could not be definitely identified. The aegirine-augite shows extinctions up to 37°, and pleochroism from pale grass-green for vibrations along the length to pale pinkish-yellow for those across the length. The cossyrite has pleochroism from nearly colourless to deep purplish-brown or opaque; the shreds were too irregular to admit of a more precise determination of the optical characters'.

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* Washington (H. S.), Chemical analyses of igneous rocks. . . . Washington, 1917, p. 315.

† *See* Washington (H. S.), op. cit. p. 561.

‡ Renard (A.), Report on the rock specimens collected on oceanic islands during the voyage of H.M.S. *Challenger*, during the years 1873–1876. Challenger Report, Physics and Chemistry, vol. 2, 1889, pp. 130 and 136.

622. Minna Bluff. A dark-green phonolitic rock (Prior, op. cit. p. 116), with buffy olive feldspars up to nearly 1 cm. in length in an aphanitic slate-olive groundmass. Prior writes:

'It shows under the microscope numerous long prismatic phenocrysts of orthoclase and anorthoclase in a very fine-grained base consisting of a mesh of minute felspar-needles with globulites and microlites of green aegirine-augite. Small crystals of this mineral are also included in the porphyritic felspars, and occur sparingly as phenocrysts. The anorthoclase-phenocrysts show no twin-striations, but have mottled extinctions; the refraction is not appreciably higher than that of Canada balsam'.

The feldspar phenocrysts have refractive indices less than Canada balsam and have most of the characters of sanidine but they do show in some sections the faint twinning seen in anorthoclase. They are optically negative.

The pyroxene of the phenocrysts is light grape-green diopside, non-pleochroic, $c:\gamma=39^\circ$ on the best longitudinal section seen. With it are associated microphenocrysts of magnetite. In the groundmass the pyroxenes are very minute, as indicated by Prior's description, and are very pale green. The whole groundmass is extremely fine-grained. Microchemical tests show it to be quite rich in nepheline. Cracks in the rock are filled with opaline silica.

A rather similar rock from Cape Bird which contained hornblendic inclusions described by J. Allan Thomson, has been recorded by Jensen as a 'trachyphonolite' [P. 341(653)] (op. cit. p. 119). It contains many scattered brown hornblende crystals.

530 from Black Island is a phonolitic trachyte characterized by patches of soda-amphiboles among which riebeckite is prominent. Microchemical tests confirm the presence of soda-feldspathoids. The hand-specimen is pale olive-grey, compact, traversed by brown cracks and patches. The feldspar laths are very slender and the majority do not exceed 0·1 mm. in length.

Prior's description (op. cit. p. 116) is as follows:

'Under the microscope it shows . . . a fine-grained trachytic felt of felspar-laths, with much deep-blue riebeckite-like hornblende scattered in minute shreds through the section, and accumulated in patches round small altered crystals of what was once probably nepheline. The riebeckite shows pleochroism from pale-brown to colourless across the length of fibres to indigo-blue along the length'.

The dark minerals are much altered in some patches, but cossyrite, and probably also aegirine, are present in addition to riebeckite.

Lastly we must mention the white phonolitic trachyte [607] from the middle of the crater of Brown Island. The feldspars in this rock are short and stout, and the rock has something of the character of an orthophyre. Prior's description (op. cit. p. 115) is as follows:

'It is a white, friable rock, resembling a domite. It consists of a fine-grained aggregate of small felspars (mostly short rectangular, but some lath-shaped) without flow-structure, in the interstices of which are distributed a few magnetite-grains and, very sparingly, needles of dull-green aegirine-augite; a few grains of aegirine and small crystals of sphene are also present. The felspars have a refraction near that of Canada balsam, and are doubtless mainly anorthoclase. With a high power, under the microscope, are seen numerous minute and very thin hexagonal and square sections of an undetermined mineral, which is isotropic or only very feebly doubly-refracting, and has a refraction markedly less than that of Canada balsam. That nepheline is present in the base, although it cannot be definitely distinguished, is indicated by the chemical analysis of the rock. . . .' The analysis is reproduced in column 5, Table I*a*. Some of the feldspars show zoning on the (010) face as well as rather indefinite twin lamellae. The refractive index for vibrations across the laths is very near that of balsam and possibly higher, while for vibrations along the length it is frequently seen to be less. The pyroxenes give extinctions $c:\alpha$ up to 30°. Pleochroism; α leaf-green, β olive-lake, γ deep grape-green. Absorption, $\alpha > \beta > \gamma$. These characters correspond to aegirine-augite. The idiomorphic crystals mentioned by Prior as so abundant are the same as have been referred to sodalite in other rocks described above. The associated rock from the crater lip [606] (Ferrar, op. cit. p. 15) is a trachyte with abundant insets of resorbed hornblende and, in the groundmass, abundant, pale yellow, small prisms of aegirine-augite.

TABLE I.—CHEMICAL ANALYSES, NORMS, ETC. OF PHONOLITIC TRACHYTES AND TRACHYTOID PHONOLITES

1. Phonolitic trachyte (Mount Cis type). ″II.6.1.3″.
   Mount Cis, Mount Erebus, Ross Island. D. I. Bothwell, anal. [J13, 1922 = BM. 1911, 135, 13].
2. Phonolitic trachyte, also 'Trachyphonolite', Jensen, 1916.
   ″II.5.1(2).3(4). Mount Cis, Mount Erebus, Ross Island. Hogarth anal. [J13].
3. Trachytoid phonolite, 'Phonolitic trachyte', Prior, 1907. (Trachydolerite in Washington, 1917, p. 317). I(II).6.1.″4.
   Cape Crozier, Mount Terror, Ross Island. G. T. Prior, anal. [188].
4. 'Phonolitic trachyte', Prior, 1907. ″II.″6.(1)2.4.
   (Trachydolerite in Washington, 1917, p. 573.)
   Scott Island, Antarctic, 67° 24′ S., 179° 55·5′ W. G. T. Prior, anal. [973].
5. 'Phonolitic trachyte', Prior, 1907. I.6.1.4.
   Washington, 1917, p. 317. Brown Island, Ross Archipelago. G. T. Prior anal. [607].
6. Trachytoid phonolite, 'Hornblende-trachyte', Prior, 1907. (I)II.6.1″.4.
   Washington, 1917, p. 563. Observation Hill, Hut Point, Ross Island. G. T. Prior, anal. [277].
7. Trachytoid phonolite, 'Altered Phyro-hornblende Trachyte', Jensen, 1916.
   II.6.″2.4. Cape Bird, Ross Island. Burrows and Walkom, anal. [J18].
8. 'Trachy-andesite', Jensen, 1907. (I)II.5.(1)2.3.
   Timor Ledges, Warrumbungle Mountains, New South Wales. H. I. Jensen, anal. [W.1.].

TABLE I*a*.—CHEMICAL ANALYSES

	1	2	3	4	5	6	7	8
SiO_2	58·90	58·94	57·95	55·93	58·64	55·47	52·54	58·95
TiO_2	1·29	1·40	0·40	0·64	0·28	1·32	1·44	0·76
Al_2O_3	16·24	16·33	20·43	19·61	22·55	20·67	19·41	17·04
Fe_2O_3	3·56	2·48	3·43	1·75	0·97	2·83	2·90	2·80
FeO	4·43	5·54	1·35	6·32	0·99	1·86	5·31	4·66
MnO	0·18	0·21	0·07	0·13	trace	0·02	0·23	0·05
MgO	0·77	1·03	0·26	0·50	0·16	1·43	1·91	0·57
CaO	2·27	2·10	1·90	3·53	1·43	3·43	4·60	2·49
Na_2O	5·60	5·54	8·32	7·75	9·87	8·33	7·50	4·51
K_2O	5·85	5·25	5·96	3·67	4·98	4·86	3·49	6·39
$H_2O + 110°$	0·28	0·42	0·39	0·19	0·35	0·12	0·16	1·28
$H_2O -$	0·54	0·44	0·23	0·10	0·08	0·08	0·08	0·59
P_2O_5	0·12	0·57	0·07	0·12	trace	0·03	0·26	abs.
CO_2	nil	0·05	—	—	—	—	0·20	0·06
ZrO_2	0·02	0·22	—	—	—	—	—	0·17
SO_3	—	0·16	—	—	—	—	—	trace
SrO	0·02	—	—	—	—	0·01	—	abs.
	100·35							
less O for Cl and F	0·033							
Totals	100·32*	100·68	100·76	100·24	100·30	100·46	100·03	100·33†

* No. 1 includes F′ 0·04, Cl′ 0·07, S″ nil, (Ce, Yt) $_2O_3$ 0·09, BaO 0·057, also the following heavy metal oxides—Li_2O, Cr_2O_3, V_2O_3, CoO nil; MoO_3 0·0011, CuO 0·017, ZnO 0·006, PbO 0·0027, NiO 0·0002.

† No. 8 includes NiO 0·05, CoO 0.01.

TABLE I*b*.—C.I.P.W. NORMS

	1	2	3	4	5	6	7	8
Q	—	0·78	—	—	—	—	—	1·26
or	34·75	30·86	35·58	21·68	29·47	28·91	20·57	37·81
ab	45·38	45·27	35·63	39·56	38·77	30·39	32·49	38·25
an	2·22	5·00	0·56	7·78	2·50	4·73	10·29	7·23
ne	0·68	—	18·74	14·06	24·42	21·58	15·34	—
hl	0·12	—	—	—	—	—	—	—
ac	—	—	—	—	—	—	—	—
di	6·8	1·65	1·51	7·77	1·86	7·78	8·75	4·55
wo	—	—	2·90	—	0·93	0·93	—	—
hy	—	7·82	—	—	—	—	—	3·94
ol	1·4	—	—	5·05	—	—	4·41	—
mt	5·24	3·71	3·48	2·55	1·39	2·09	4·18	4·18
il	2·43	2·74	0·76	1·22	0·61	2·58	2·74	1·52
hm	—	—	0·96	—	—	1·44	—	—
ap	0·34	1·34	—	0·34	—	—	0·67	—
cc	—	—	—	—	—	—	—	—
nc	—	0·11	—	—	—	—	0·53	—
th	—	0·28	—	—	—	—	—	—
z	0·04	0·37	—	—	—	—	—	—
Kp	24·3	22·75	22·5	16·3	18·1	20·5	17·1	27·7
Ne	31·2	32·0	42·3	47·0	48·7	47·3	48·2	26·8
Q	44·3	45·0	35·0	36·2	22·8	32·7	34·7	45·2
	99·8	99·75	99·8	99·5	99·6	100·5	100·0	99·7

TABLE I*c*.—CHEMICAL ANALYSES EXPRESSED AS CATION PER CENT.

	1	2	3	4	5	6	7
SiO_2	54·74	54·5	51·66	51·5	51·26	49·23	47·69
TiO_2	0·9	1·0	0·27	0·46	0·21	0·92	0·98
$\frac{1}{2}Al_2O_3$	17·75	17·75	21·5	21·25	23·3	21·7	20·75
$\frac{1}{2}Fe_2O_3$	2·52	1·77	2·25	1·22	0·63	1·92	1·96
FeO	3·45	4·28	1·55	5·0	0·74	1·39	4·04
MnO	—	0·17	—	—	—	—	0·16
MgO	1·07	1·44	0·375	0·70	0·21	1·92	2·61
CaO	2·25	2·11	1·82	3·5	1·32	3·23	4·46
$\frac{1}{2}Na_2O$	10·0	9·95	14·4	12·08	16·78	14·38	13·2
$\frac{1}{2}K_2O$	7·0	6·18	6·85	4·26	5·60	5·56	4·04
$\frac{1}{2}P_2O_5$	0·11	0·44	—	0·11	—	—	0·22
SO_3	—	0·22	—	—	—	—	—
ZrO_2	—	0·11	—	—	—	—	—
SrO	0·04	—	—	—	—	—	—
BaO	0·02	—	—	—	—	—	—
CO_2	—	0·05	—	—	—	—	—
Totals	99·85	99·97	100·68	100·08	100·05	100·25	100·11

TABLE I*d*.—EQUIVALENT NORMS

	1	2	3	4	5	6	7
Q	—	—	—	—	—	—	—
Or	35·0	30·90	34.25	21·30	28·0	27·80	20·20
Ab	48·15	49·75	35·27	45·30	38·68	30·35	32·30
An	1·87	4·05	1·25	12·25	2·30	4·40	8·78
Ne	1·11	—	22·03	9·06	27·13	24·93	20·22
Wo	3·4	1·14	3·14	1·72	1·72	4·70	4·68
En	1·54	2·76	0·74	0·26	0·42	3·82	2·52
Fs	1·86	4·90	0·32	1·46	0·44	—	2·16
Fo	0·45	0·09	—	0·85	—	—	2·02
Fa	0·54	0·18	—	4·80	—	—	1·74
Il	1·8	1·17	0·54	0·92	0·42	1·84	1·96
Mt	3·78	2·66	3·37	1·83	0·94	1·41	2·94
Hm	—	—	—	—	—	0·98	—
Ap	0·3	1·17	—	0·3	—	—	0·59
Totals	99·8	99·70	100.91	100·05	100·05	100·23	100·11
Or	41·1	36·5	48·5	27·2	40·6	44·7	42·2
Ab	56·7	58·9	50·0	57·8	56·1	48·5	45·4
An	2·2	4·8	1·8	15·6	3·3	7·0	12·3

TABLE I*e*.—‘NIGGLI VALUES’

	1	2	3	4	5	6	7
si	203	205	192·8	177	200	169	148
al	33	33·3	40	36.4	45	37	32·5
fm	27	28·7	14	23·7	6	18	27
c	8·5	7·9	6·5	11·9	5	11	14
alk	31·5	30·2	39·5	28·0	43·5	34	26·5
ti	3·3	3·7	1·0	1·5	0·8	3·1	3·0
k	0·41	0·38	0·32	0·26	0·33	0·28	0·25
mg	0·15	0·19	0·1	0·1	0·13	0·36	0·3
c/fm	0·315	0·275	0·465	0·51	0·83	0·61	0·52
qz	− 27·5	− 25	− 67	− 60·35	− 78·5	− 76	− 76
p	0·2	0·83	0·1	0·2	—	0·04	0·34

TABLE I*f*.—‘BASIS’

	1	2	3	4	5	6	7
Z	—	0·22	—	—	—	—	—
Cp	0·28	1·12	—	0·28	—	—	0·55
Ru	0·9	1·0	0·3	0·44	0·21	0·9	0·93
Kp	20·95	18·6	20·5	12·8	16·7	16·6	12·1
Ne	30·25	29·8	43·0	36·2	50·3	42·8	39·5
Cal	1·18	2·56	0·3	7·35	1·62	2·7	5·23
Cs	2·52	0·89	2·6	1·33	1·62	3·5	3·6
Fo	1·62	2·17	0·5	1·0	0·31	2·9	3·93
Fa	5·35	6·69	1·6	7·48	1·1	2·1	6·25
Fs	3·8	2·67	3·4	1·83	0·9	2·9	2·95
Q	33·3	34·3	27·8	31·4	27·7	25·6	25·0
	100·15	100·02	100·0	100·11	100·46	100·0	100·04
L	52·38	50·96	63·8	56·35	68·62	62·1	56·83
M	14·19	13·42	8·47	12·08	4·14	12·3	17·66

III. KENYTES

The observation that among the volcanic rocks of South Victoria Land were some with characters similar to some of the volcanic rocks of the Rift Valley of East Africa was made by G. T. Prior* in 1902 when describing the rock-specimens collected by the 'Southern Cross' Antarctic Expedition of 1899–1900. Among the boulders collected by Louis Bernacchi and other members of the expedition at Winter Quarters on Cape Adare was one that Prior described as approaching 'closely to the rocks from Mount Kenya to which Prof. Gregory has given the name "Kenyte" '. It is rather a weathered, flat boulder about 14 cm. across and is the only one of its kind in the collection [BM. 85752, 24].

This seems to be the first mention of kenyte in Antarctica. The feldspars in this rock do not show the lenticular habit of the rhomb-porphyries, which has come to be regarded as typical of Antarctic kenytes, but in the same year as that in which Prior published his observation quoted above, H. T. Ferrar on the 'Discovery' Expedition of 1901–4 was finding among the basalts of Ross Island porphyritic lavas with just such lenticular feldspars in great abundance. When G. T. Prior described these specimens five years later he recognized them at once as exhibiting characters 'almost precisely identical with those of the rhomb-porphyries of Norway and the more recent kenytes of Mounts Kenya and Kilimandjaro in East Africa'.†

After describing the rocks he wrote (op. cit. p. 111): 'They are almost precisely identical in characters and chemical composition with the kenytes of Mount Kenya, and the description recently published by Dr Finckh of the rhomb-porphyries (kenytes) of Kilimandjaro could be followed almost word for word in an account of these Antarctic rocks. They are alkaline basalts or trachydolerites (Rosenbusch), intermediate in type between ordinary basalts and phonolites'. Chemical analysis of a specimen from Cape Royds established its very close similarity in chemical composition with the nepheline-rhomb-porphyry from Vasvik, Norway, and a slightly less close similarity with a 'leucite-rhomb-porphyry' from Kibo, Kilimandjaro, and a typical kenyte from Mount Kenya. The feldspar of the lenticular insets was identified as anorthoclase. Nepheline was not found as insets nor could it with certainty be detected in the groundmass though its presence was indicated by the bulk analysis. On the other hand Prior (op. cit. p. 111) observed in the groundmass 'fairly numerous, small, rounded isotropic crystals of leucite . . .'.

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* Prior (G. T.), Report on the rock-specimens collected by the 'Southern Cross' Antarctic Expedition *in* Report on the collections of Natural History made in the Antarctic Regions during the voyage of the 'Southern Cross'. London, 1902, p. 329.

† Prior (G. T.), Nat. Ant. Exp. 1901–1904. Nat. Hist., vol. 1, Geology, 1907, p. 102.

The section of the chapter in which Prior described these rocks is headed 'Kenytes (Trachydolerites, Alkaline-basalts, Rhomb-porphyries)' and the implication appears to be that Prior regarded these names in brackets as alternatives or at least as indicating the position of the kenytes in current rock classification.

Jensen* used the name kenyte not only for the lavas with lenticular phenocrysts of anorthoclase described and named kenyte by Prior but also for lavas similar in most respects to these but containing 'rounded oligoclases of tabular habit'. For these he proposed the name 'basic kenytes' distinguishing the others as 'acid kenytes'.

Such an extended use of the name 'kenyte' is in conformity with its original use by J. W. Gregory,† who applied the name to several porphyritic lavas on Mount Kenya of different kinds including some with phenocrysts of potash-oligoclase similar to Jensen's 'basic kenytes', while others with lenticular anorthoclase resembled the 'rhomb-porphyries' of Kilimanjaro. If the name 'basic kenyte' is found to be useful there is no great objection to Jensen's proposal, but the name 'kenyte' without prefix should be understood to apply only to rocks closely resembling that type of lava with lenticular or rhomb-shaped phenocrysts of anorthoclase from Mount Kenya analysed by Prior (1903, p. 246), those from Ross Island described and analysed by Prior, and the more extensive series from Mount Erebus and Ross Island later described by Jensen as 'acid kenytes', It is only the 'kenytes' as so defined which are described in this section.

It is now known that there is an important difference between the rocks of Mount Kenya named kenyte by J. W. Gregory and the lavas of Mount Erebus to which Prior extended the name.‡ The kenytes of Mount Kenya actually contain large insets of nepheline. These occur as large, stumpy prisms up to 1 cm. in length and are not at all obvious or easy to distinguish at a glance from the feldspar insets which are often rectangular in outline. They had eluded the observation of Gregory and Prior and it was not until the East African volcanic rocks were being revised that these nepheline insets were discovered.

No such nepheline insets have been found in any of the Mount Erebus 'kenytes', and one is faced with an awkward predicament. The name 'kenyte' has been applied in all good faith to the rocks of Mount Erebus with the lenticular feldspars and it is now found that they lack one of the essential characteristics of the type specimens from Mount Kenya.

Elsewhere§ it has been suggested that 'It may be advisable to restrict the name "kenyte" to rocks like those round the central plug of Mount Kenya (to which Gregory first gave the name) in which large crystals of anorthoclase (and nepheline more rarely) lie in a black, glassy base', but the name 'kenyte' is in such general use and is so well established as a name for the rocks of Mount Erebus that such a proposal would be unwelcome and would not be adopted.

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* Jensen (H. I.). Brit. Ant. Exp. 1907–9, Geology, vol. 2, 1916, pp. 103–109.

† Gregory (J. W.), Quart. Journ. Geol. Soc., 1900, vol. 56, p. 209.

‡ Smith (W. Campbell), Quart. Journ. Geol. Soc., 1931, vol. 87, p. 242.

§ Smith (W. Campbell), Bull. Brit. Mus. (Nat. Hist.), Mineralogy, vol. 1, no. 1, 1950, p. 8.

The situation is somewhat like that which arose over the so-called essexites of the Oslo region so named by Brøgger in 1898. Barth's revision of the systematic petrography of the plutonic rocks of the Oslo region brought out the fact that the 'essexites' of Oslo usually carry no nepheline whereas the type essexite of Salem Neck, Essex County, Massachusetts, carries nepheline in fair abundance (10%). Barth wished to propose the name kauaiite in place of 'essexite' for the Oslo rocks but realizing that such a change would mean a great innovation for Norwegian geologists he proposed as a compromise to use the name 'Oslo-essexite' always bearing in mind the distinction between 'Oslo-essexite' and the original essexite of the Essex County type of rock.* He himself, however, went on to use 'Oslo-essexite' more loosely as a group name including quite a range of rocks occurring in the old volcanic bosses of the Oslo region.

One might perhaps adopt a similar device for the kenytes of Mount Erebus and refer to them as Erebus-kenytes or Antarctic-kenytes bearing in mind that they differ in one essential from the kenytes of Mount Kenya. It would be even simpler to refer to them in the field as 'rhomb-porphyries' and to describe them systematically as porphyritic anorthoclase-phonolites (Erebus type), but one feels, as Barth did about the essexites, that whatever alteration in the name one proposes will be rejected, and to all who know these Erebus rocks in the field and in petrographical collections kenytes they are and kenytes they will remain.

Description of the hand-specimens

The kenytes of Ross Island are porphyritic, usually somewhat vesicular or drusy, with very abundant insets of feldspar ranging up to 3 cm. in length and usually lozenge-shaped in section (Pl. 2, Fig. 1). Prior gave a line drawing of a specimen from Turtle Back Island (op. cit. fig. 62) and David and Priestley figured a weathered boulder from the moraine at Cape Royds (op. cit. 1914, pl. 57, fig. 1).

As described by Jensen the groundmass varies from 'holocrystalline . . . to hypocrystalline (hyalopilitic), hemicrystalline (vitrophyric), and holohyaline' (op. cit. p. 105). In colour it varies from dark olive-grey in the holocrystalline to shiny black in the holohyaline, wholly glassy, specimens. Some specimens are vinaceous brown to brick-red, possibly where lavas have been exposed to escaping volcanic gases. The extremely vesicular type from Hooper's Shoulder on Erebus has abundant feldspar insets in a black iridescent glass, and the spongy pumice that forms the matrix of the large anorthoclase crystals found at the summit of Erebus and on the floor of the second crater is dark brown, almost black (Pl. 1, Fig. 2). A block of this pumice was figured by David and Priestley (op. cit. pl. 64, fig. 1).

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* Barth (Tom. F. W.). Skrift. Norske Vidensk. Akad. Oslo, I. Mat.-Naturv. Kl., 1944, No. 9 (1945), pp. 29–31.

This brown pumice is extremely friable, and is very difficult to transport, but nevertheless, some large pieces were brought back by the Expedition. At first sight it appears to contain no phenocrysts but closer examination reveals anorthoclase crystals, so completely coated with pumice as to be distinguishable only with difficulty in the hand-specimen.

Description of the thin sections

The Insets (*phenocrysts*)

The insets in the kenytes, in addition to the well-known and very abundant feldspars, comprise small olivines, pyroxene, rather less frequent than the olivine, and very small crystals of opaque 'ores', probably ilmenite and magnetite.

The FELDSPARS occur as good crystals bounded by the forms M $(1\bar{1}0)$, m (110), and y $(\bar{2}01)$ and giving the well-known lozenge- or rhomb-shaped sections on some cleavage faces. They are quite similar in habit to the abundant insets of the rhomb-porphyries of the Oslo region of Norway.

Prior* was the first to describe these crystals from the Antarctic. He identified them as anorthoclase following Rosenbusch† and Finckh‡, who had applied the name to the insets in the Oslo rhomb-porphyries and to the somewhat similar crystals in some of the lavas of Kilimanjaro.

Prior's description of the feldspar insets is as follows: 'They almost invariably show minute twin-striations, occasionally in two rectangular directions according to the albite- and pericline-laws. Like the similar phenocrysts in the kenytes of Mount Kenya, they contain numerous inclusions of glassy base, and also occasionally inclusions of olivine, augite, apatite, and magnetite or ilmenite.... In physical characters they agree perfectly with the anorthoclases of Pantelleria and Kilimandjaro. The specific gravity is 2·62. Cleavage-flakes parallel to b(010) show a positive bisectrix, slightly inclined, and give an extinction angle with the trace of c(001) of about 6°, while cleavage-flakes parallel to c(001) have extinctions of about 1°. The refraction was about the same as clove-oil (1·538). Wolff (quoted by Finckh) found the value of γ for the anorthoclase of Kilimandjaro to be 1·5376'.

E. D. Mountain§ thoroughly investigated the crystals found loose on the crater slopes of Mount Erebus, utilizing material collected by members of the 'Terra Nova' Expedition. He used sections ground parallel to the cleavage faces and also cut at right angles to both cleavages. Analyses were made on portions of the same crystals. The extinction angles differ from those given by Prior but specific gravity and refractive indices agree. Mountain's values are as follows:

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* Prior (G. T.), op. cit. 1907, p. 112.

† Rosenbusch (H.), Mikroskopische Physiographie.... 1905, vol. 1, part 2, p. 329.

‡ Finckh (L.), Die Rhombenporphyre des Kilimandscharo. Festschrift Harry Rosenbusch..., 1906, p. 375.

§ Mountain (E. D.), Potash-oligoclase from Mt. Erebus, Antarctic, and anorthoclase from Mt. Kenya, East Africa. Min. Mag., 1925, vol. 20, pp. 331–45.

> The cleavage angle (001): (010), measured on very small fragments from three different crystals, averaged 87°, 89° 45′, and 88°.
>
> Extinction on (001) measured on sections from the three crystals: 2·3°–4·5°, average 3·4°; average 2·7°; and 1·8°–3·2°, average 2·6°.
>
> Extinction on (010): 3·4°–5·9°, average 4·7°; 1·8°–3·2°, average 2·6°; and 3·7°.
>
> Refractive indices; α 1·536, β 1·539, γ 1·541. 2V 62°. Sp. gr. 2·620.
>
> The chemical analyses, which are quoted in columns 9 and 10 in Table II*a*, correspond to the formulae Or: Ab: An = 18:64:18 for one and 19:64:17 for the other analysis.

On the basis of these compositions Mountain, following H. L. Alling, classified the feldspar as potash-oligoclase. The corresponding crystals (insets) in the kenytes of Mount Kenya, with a little less CaO and a little more K_2O, fall, however, in the composition range suggested by Alling for 'anorthoclase'.

By examining on the universal stage the sections used by Mountain it has been possible to confirm the orientation and the extinction angles, cleavage angle, and apparent optic axial angle as obtained by him on specially oriented sections. The optic axial plane is approximately parallel to (001). Albite-lamellae are very well developed and, as C. Oftedahl remarks, are best observed in a section normal to the axis [100]. Some of the albite lamellae are wide enough to allow a measurement to be made of the extinction angle, but it has not proved possible to determine the orientation of the principal planes by the classical Fedorov method. Some broad lamellae that appear at first sight to be quite simple give the impression in certain positions and lighting that they are actually crossed by sub-microscopic lamellae. The cleavage angle 001:010 is so near 90° that it is difficult to decide whether extinction angles measured in the plane at right angles to them, ⊥ to [100], should be read as 'positive' or 'negative' and the angles accordingly do not give unambiguous results. The extinction angles obtained could be interpreted as indicating a plagioclase with An_{10}, but the value of the apparent optic axial angle, 62°, which was confirmed by several new measurements on the universal stage, is quite abnormal for any plagioclase.

The Mount Erebus feldspars were not among those studied by Edmondson Spencer in his first examination of the stability relations of alkali-feldspars.* They are in composition outside the range either of his orthoclase-microperthites or microcline-microperthites in none of which does the orthoclase fall below 43 per cent nor the albite rise above 51 per cent. Edmondson Spencer did, however, give careful consideration in his second paper to what he described† as 'Mountain's series', i.e. $Ab_{65}Or_{35}$–$Ab_{65}An_{35}$ and he made new analyses and measured the optic axial angle of three feldspars in the same range of composition as those from Mount Erebus (including one from Mount Kenya).

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* Spencer (Edmondson), Min. Mag., 1930, vol. 22, pp. 291–367.

† Spencer (Edmondson), Min. Mag., 1937, vol. 24, p. 489.

E. Spencer came to the conclusion that there was a discontinuity in the potash-soda-feldspar series above 60 per cent of the soda-component (op. cit. p. 490) and that 'with the amount of lime usually present in crystallizing magma, homogeneous potash-soda felspars are not produced' between the limits Ab_{50-60} and Or_{30-20} in the Ab-Or-An feldspars.

Mountain thought of the Erebus crystals and others like them as 'undercooled solid solutions due to crystallization in a very viscous magma in the presence of mineralizers and to relatively rapid cooling precluding diffusion and exsolution'. He favoured the early view advocated by Mallard and A. Michel-Lévy that the apparent monoclinic symmetry of these feldspars, especially as indicated by cleavage angles near 90°, was due to sub-microscopic twinning of a truly triclinic structure but he noted that the effect of the twinning on the extinction angles remained obscure (op. cit. pp. 340–1).

The actual temperature at which the 'anorthoclase' crystals, both of Mount Erebus and Mount Kenya, become (or appear to become) monoclinic has been determined by W. Scott Mackenzie using an X-ray method which is described in his paper.*

The inversion temperature for the Mount Erebus crystals, $Or_{17\cdot9}\ Ab_{63\cdot2}\ An_{18\cdot9}$, Mackenzie found to be 600° C., not very far removed from the inversion temperature (540°) he determined optically and by the X-ray method for anorthoclase, $Or_{23}Ab_{69\cdot5}\ An_{7\cdot51}$, from a soda-trachyte from Ropp, Nigeria, recently described by J. R. F. Joyce and P. M. Game.†

The synthetic crystals comparable to the Mount Erebus feldspars, $Or_{20}Ab_{70}An_{10}$, hydrothermally crystallized, have an inversion temperature of 675° C. This is very much higher than the inversion temperature proper to $Or_{20}An_{80}$ on the curve plotted for the simple binary system (op. cit. fig. 3). On the other hand the temperature determined for anorthoclase from Mount Kenya, $Or_{28\cdot1}Ab_{61\cdot8}An_{10\cdot1}$, 140° C., is 35° *lower* than that for the synthetic, hydrothermally crystallized $Or_{30}Ab_{70}$ but 40° *higher* than the inversion temperature determined for crystals $Or_{31\cdot7}Ab_{68\cdot5}An_{1\cdot8}$ from the Azores (op. cit. table 2).

Since Mountain's paper was published the feldspar insets of the rhomb-porphyries, which the Mount Erebus, Kenya, and Kilimanjaro feldspar have always been thought to resemble, have been investigated by E. Baier‡ and E. Ljungner § and more recently by C. Oftedahl.||

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* Mackenzie (Wm. Scott), Amer. Journ. Sci., 1952, Bowen Volume, Part 2, pp. 319–342.

† Joyce (J. R. F.) and Game (P. M.), Bull. Brit. Mus. (Nat. Hist.), Mineralogy, Vol. 1, No. 3, 1952, pp. 85–91.

‡ Baier (E.), Lamellenbau und Entmischungsstruktur der Feldspat. Zeits. Krist., 1930, vol. 73, pp. 530–1 and fig. 9.

§ Ljungner (E.), Bull. Geol. Inst. Upsala, 1930, vol. 21, pp. 45–55.

|| Oftedahl (C.), Studies on the igneous rock complex of the Oslo region. VI. On akerites, felsites and rhomb porphyries. Skrift. Norske Vidensk. Akad. Oslo, 1, Mat.-Nat. Kl. 1946, No. 1, pp. 37–49; also IX. The feldspars. Ibid. 1948, No. 3, pp. 9 *et seq.*

Oftedahl, using the universal stage, found that the optical properties considered characteristic of 'anorthoclase' are due to very fine albite-twin lamellae, and that according to refractive index measurements using the immersion method the main feldspar of the insets in the Oslo rhomb-porphyries is plagioclase of composition An_{30-40} but that they contain from 5 to 20 per cent of an antiperthite component in detached patches that are often spotted and cloudy. In another type the insets 'are selvaged by a broad zone of alkali-feldspar which passes over into the groundmass with gradual transitions' (op. cit. 1946, p. 37).

An analysis of insets from the rhomb-porphyry dike at Tyveholmen in the Oslo region is given in column 12, Table II*a*. The extinction angle, $a:\alpha$, measured by Oftedahl is 8° and 2V(–) 80°. The mode of the feldspar is calculated as, $Or_{28\cdot1}$ $Ab_{53\cdot3}$ $An_{18\cdot6}$, but Oftedahl finds 30–50 per cent antiperthitic alkali-feldspar in the insets seen in a thin section, and the refractive indices determined by the immersion method indicate An_{30-40} for the main plagioclase component.*

Oftedahl attempted a similar explanation of the feldspar insets in the Kilimanjaro rhomb-porphyries and the insets in a 'rhomb porphyry from Mount Erebus' in W. C. Brøgger's collection and suggested that the crystals were albitic perhaps with a rim of alkali-feldspar in the case of the Kilimanjaro insets. However, the optic axial angles, around 60°, are quite abnormal and the refractive indices and extinction angles measured on (001) and (010) cannot be consistently matched with any plagioclase, and it is difficult to see what optical measurement can be trusted to give the composition of the plagioclase component. In the Oslo rhomb-porphyries antiperthitic alkali-feldspar is visible but it appears that Oftedahl envisages cryptoperthites composed of sub-microscopic lamellae of orthoclase and albite twinned on the albite-law and resulting in an apparently monoclinic form.

Further X-ray work on the Mount Erebus and Mount Kenya crystals may ultimately resolve some of these problems. So far as I am aware X-ray studies other than the observations made by W. Scott Mackenzie to determine inversion temperatures have not been made on the Mount Erebus or Mount Kenya crystals. They were not included in the series of potash-soda-feldspars examined by Chao, Smare, and Taylor†, who used only E. Spencer's 'orthoclase-microperthites'.

The important work of O. F. Tuttle‡ on 'Optical studies on alkali feldspars' does not directly throw light on the Mount Erebus feldspars as the high anorthite-content of the latter really removes them from the range of compositions studied by Tuttle. Admittedly Tuttle included in his list the analysis by Edmondson Spencer of feldspar from Kenya and the analyses by E. D. Mountain quoted by him, but optical properties of the Mount

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* The equivalent normative composition of this feldspar is plotted at No. 12 on a triangular Or-Ab-An diagram (Fig. 3) on which are also plotted the equivalent normative compositions of the potash-oligoclase of Erebus and the anorthoclase of Mount Kenya analysed by Mountain.

† Chao (S. H.), Smare (D. L.) and Taylor (W. H.), Min. Mag., 1939, vol. 25, pp. 338–350.

‡ Tuttle (O. F.), Amer. Journ. Sci., 1952, Bowen Volume, Part 2, pp. 553–567.

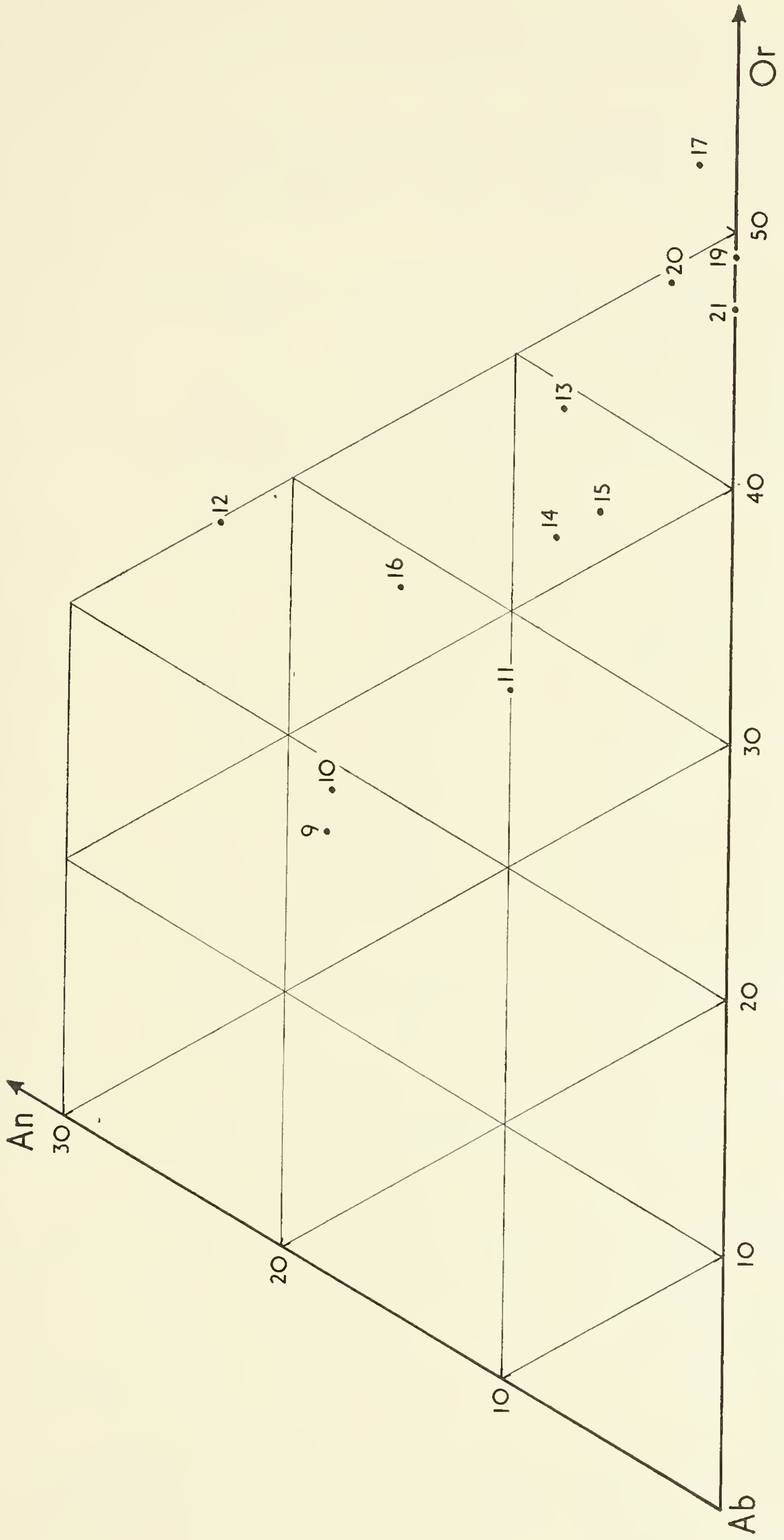

Fig. 3. Normative compositions of feldspars in the kenytes. The point representing the insets in the rhomb-porphyry dike at Tyveholmen in the Oslo region, Norway, is shown at 12.

Erebus crystals, when plotted against Or:Ab + An, fall far wide of the curves obtained by Tuttle either for his 'orthoclase-cryptoperthites' or his sanidine-anorthoclase-microperthites.

For the purpose of this purely petrographic paper it seems best to refer to the Mount Erebus feldspars as 'anorthoclase', leaving it to be understood that they may in fact be oligoclase with a high potash content, 'potash-oligoclase' as defined in Mountain's paper.

TABLE II.—CHEMICAL ANALYSES OF FELDSPARS

9. Potash-oligoclase (E. D. Mountain, type 1), Mount Erebus.
10. Potash-oligoclase (E. D. Mountain, type 2), Mount Erebus.
11. Anorthoclase, Mount Kenya, 'in tuffs on the slopes of the crater'. Analyst 9, 10, and 11. E. D. Mountain. Min. Mag., 1925, vol. 20, p. 336.
12. Phenocrysts of rhomb-porphyry dike, Tyveholmen, Oslo region, Norway. Anal. A. Thorkildsen. (C. Oftedahl, Skrift. Norske Vidensk. Akad. Oslo, I. Mat.-Nat. Kl., 1946, No. 1, p. 24.)

TABLE II*a*.—CHEMICAL ANALYSES

	9	10	11	12
SiO_2	62·79	62·49	64·33	53·75
TiO_2	—	—	—	—
Al_2O_3	22·12	21·86	20·94	29·94
Fe_2O_3	0·36	0·30	0·20	
FeO	0·41	1·31	0·58	
MnO	—	—	—	—
MgO	—	0·16	—	1·18
CaO	3·76	3·74	2·01	4·06
Na_2O	7·35	7·20	7·22	4·84
K_2O	2·98	3·26	4·71	3·85
$H_2O + 110°$	0·19	0·04	0·27	—
$H_2O - 110°$	0·07	—	0·10	—
P_2O_5	—	—	—	—
	100·03	100·36	100·36	97·62
Sp. gr.	2·620	2·620	2·602	—

TABLE II*b*.—C.I.P.W. NORMS

	9	10	11
or	17·8	19·24	27·9
ab	62·1	60·2	60·6
an	18·7	17·8	10·1
mt	0·6	0·46	0·2
$FeSiO_3$	0·5	di. 0·73	—
Q	0·4	—	—
ol	—	1·63	(Fa) 0·7
ne	—	0·5	0·2
	—	—	C 0·3
	100·1	100·56	100·0

TABLE II*c*.—CATION PER CENT

	9	10	11	12
SiO_2	56·3	55·8	57·6	50·9
TiO_2	—	—	—	0·3
$\frac{1}{2}Al_2O_3$	23·3	23	22	22·5
$\frac{1}{2}Fe_2O_3$	0·28	0·2	0·13	6·9
FeO	0·33	0·97	0·43	
MnO	—	—	—	—
MgO	—	0·21	—	1·7
CaO	3·62	3·57	1·93	4·1
$\frac{1}{2}Na_2O$	12·70	12·45	12·48	8·9
$\frac{1}{2}K_2O$	3·44	3·71	5·35	4·1
	99·97	99·96	99·92	99·4*

TABLE II*d*.—EQUIVALENT NORMS

	9	10	11	12
Or	17	18·5	26·75	23·5
Ab	63·5	61·6	62·4	44·5
An	18	17·1	9·65	20·5
Mt	0·45	0·3	0·2	6·6
Hy	0·36	Di 0·6	Hy 0·3	3·4
Q	0·5	—	—	—
	—	Ol 1·4	Ol 0·3	—
	—	—	—	Il 0·6
	—	Ne 0·4	—	—
	—	—	C 0·3	C 0·7
	99·8	99·9	99·9	99·8*
Or	17·22	19	27	—
Ab	64·50	63	63	—
An	18·25	18	10	—
	99·97	100	100	—

* Oftedahl (C.), Skrift. Norske Vidensk. Akad. Oslo, I. Mat.-Nat. Kl., 1946, No. 1, p. 42. A proportion of the total for $Al_2O_3+Fe_2O_3$ has been allotted to Fe_2O_3 and TiO_2.

The OLIVINE insets in the kenytes are as a rule allotriomorphic, generally less than 1 mm. in diameter, irregular and rounded in outline, and pale yellow in colour. A series of measurements on the universal stage gave 2V 80° ± 5°, optically –, indicating a composition around fayalite 37 ± 11%. The crystals measured were in sections of two holocrystalline kenytes [D8E and D68E] from Cape Evans and two [D6R and D15R] from Cape Royds (see Pl. 4, Fig. 2).

PYROXENE insets (Pl. 4, Fig. 3) are less frequent than the olivines. In size the largest measured was 4 mm. long. The colour in thin section is very pale, sometimes nearly colourless. Shades recorded in the nomenclature of Ridgway are: pallid purple drab; mineral grey to court grey and light mineral grey; olive-buff and pale olive-buff. An exceptional yellow pyroxene developed in one of the coarse-grained kenytes is referred to separately below.

Extinction angles measured range in twelve different sections from 22° to 47° for $c{:}\gamma$. Measurements on the universal stage on 3 sections gave 2V 60° (+) and $c{:}\gamma$, obtained graphically, 49°.

Prior described the pyroxene insets as: 'generally without distinct crystalline outline, and consist of a pale-gray or brown augite having angles of extinction over 40°'. Jensen referred to them as aegirine in J44, J40, and J25, and as aegirine-augite in J47 and J5 from Cape Evans, and also in J48, P54, and P55 (a leucite-bearing type) from Cape Royds and Cape Barne. He gives no optical data other than one extinction angle in J47 (38°).

The opaque 'ores' are tentatively referred to magnetite following Prior and Jensen, but ilmenite is definitely proved in the inclusion in kenyte [D12Eb] by an X-ray powder photograph. Some magnetite is associated with the ilmenite in this specimen. The opaque 'ores' occur only as very small crystals and rarely rank as insets.

Varieties of kenytes, (a) with holocrystalline and hemicrystalline groundmass

The mineral composition can best be made out in the most coarse-grained holocrystalline specimens, e.g.: D68E and D70E, erratics from Deviation Hill,* Cape Evans region; D26E, from the base of The Slipper, E. of Cape Evans; and Jensen's J40, from Cape Evans.

The main constituent is the feldspar, referred by both Prior and Jensen to anorthoclase, but it does not show the fine-scale twinning and it may be orthoclase. It occurs chiefly as lath-shaped Carlsbad twins ranging up to 1 mm. in length in the very coarsest grained specimens but usually less than 0·25 mm. and averaging perhaps 0·2 mm. (see Jensen, op. cit. pl. 2, fig. 2). The other colourless constituents of the groundmass are nepheline in considerable amount; some interstitial patches of sodalite or analcime, and some patches of turbid glassy base. The 'dark' minerals are olivine, grains and minute prisms of pale greyish green or pale purple-drab (D7O, D26R micro-insets) pyroxene with $c{:}\gamma = 43°$, and some aegirine, one or more soda-amphiboles, very small magnetite or ilmenite crystals and grains, and apatite (Pl. 4, Fig. 1).

One dark brown amphibole is probably cossyrite. A paler brownish one varies in colour from cinnamon to warm buff with a tinge of green and gives $c{:}\gamma = 28°$ [D68E]. Another gave $c{:}\gamma = 12°$ and pleochroism; α' tawny olive to yellowish olive, γ' dark greenish olive. Absorption, $\gamma' > \alpha'$.

Some interstices between the feldspar laths are occupied by pale yellow isotropic 'glass' of higher refractive index than the feldspar. Sometimes larger interstitial patches

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* SE. of the end of Island Lake. See Fig. 2.

[D68E] are occupied by a finer-grained variation of the groundmass in which curved, slender feldspars traverse plates of soda-amphiboles (cossyrite and another, greenish yellow in colour) and interstitial nepheline with probably sodalite. There are a few patches of turbid glassy base, some of which is seen to be enclosed by the feldspar (anorthoclase) insets.

An erratic from The Ramp,* Cape Evans, collected by Debenham [D12E] provided three specimens of a type of kenyte not hitherto described. Debenham's catalogue refers to the erratic as light greyish pink, but this description only applies to one of the three pieces collected. As regards the other two [D12E*a* and D12E*b*] small parts of the hand-specimen are dark grey, coarse-grained kenyte similar to those described above, and only irregular patches are the lighter colour. These lighter parts are deep olive-buff. It appears that they owe their colour to the presence in unusual abundance of a pale pyroxene, which is yellow in thin section.

The feldspar insets are of the characteristic shape and show the usual very fine twinning. They contain numerous inclusions round their edges and show, perhaps more than usual, inclusions of a feldspar of lower index than the host. The areas between the insets are partly 'groundmass' consisting of feldspar laths, presumed interstitial nepheline, and very small grains of iron 'ore', and pyroxene. The feldspars are very frequently in small spherulitic groups. The bright yellow pyroxene occupies areas where the feldspar (and nepheline ?) are granular and clear, and the pyroxene is closely associated with, and sometimes forms clots with, an opaque iron 'ore' and with crystals of faintly brown apatite. Some of the iron 'ore' is ilmenite (X6095).†

The pyroxene is aegirine-augite very near to acmite. The colour is straw-yellow; pleochroism very weak; extinction $c{:}\alpha$ up to 17°; refractive indices, γ' just less than 1·737, α' greater than 1·712. Sp. gr. between 3·16 and 3·27. 2V has not been measured successfully. An X-ray photograph confirmed that it is a member of the clinopyroxene series; and a spectrogram showed Na, Mg, Al, Ti, Si, Fe, Ca, with a little P, the last probably admixed apatite (X6083, spectro. 111).

Attempts to get definite measurements of $c{:}\alpha$ and 2V on the universal stage were not successful and the value given for $c{:}\alpha$ may be too low as higher, though less reliable, measurements than 17° were observed.

An analysis made of a sample of one of the specimens of D12E, shown in column A below, when compared with the analysis of a typical, coarse-grained kenyte [D70E], shows slightly higher Na_2O, Fe_2O_3, SiO_2 and lower CaO, Al_2O_3, and FeO. These differences are small and, though they operate in the right direction, they are not large enough for acmite to appear in the C.I.P.W. norm.

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* The position of The Ramp is shown in the sketch-map of Cape Evans in: Taylor (Griffith), The physiography of the McMurdo Sound and Granite Harbour region. Brit. Ant. (Terra Nova) Exp., 1910–1913 1922, fig. 82, p. 76. It is also shown in Fig. 2.

† Numbers preceded by 'X' refer to X-ray photographs in the Department of Mineralogy, British Museum (Natural History).

As the content of Fe_2O_3 in this rock is of particular importance it is unfortunate that the FeO could not be determined directly by the Pratt method. The analyst reports that when the sample used for FeO determination was attacked with HF and H_2SO_4 there remained an undissolved residue amounting to 1·36 per cent of the sample used (about 0·5 gm.). This was shown by X-ray photograph (X 6315) to be ilmenite. An amount of FeO 0·65 per cent, corresponding to 1·36 per cent ilmenite, was added to the FeO determined in the solution, 0·20 per cent, to give the figure 0·85 listed in the analysis. It will be noted that the TiO_2 1·01 per cent is more than is required for 1·36 per cent of ilmenite.

ANALYSIS OF KENYTE 'INCLUSION' FROM THE RAMP, CAPE EVANS

	A	B		Norm of A	Norm of B
SiO_2	55·80	54·92	or	27·1	27·8
TiO_2	1·01	1·31	ab	41·1	35·1
Al_2O_3	18·22	19·53	an	0·6	6·7
Fe_2O_3	5·99	4·19	ne	13·9	14·25
FeO	0·85	1·74			
MnO	0·24	0·21			
MgO	1·17	1·07	di	4·5	5·83
CaO	2·78	3·48	wo	0·6	0·93
Na_2O	8·13	7·48	ol	—	—
K_2O	4·58	4·73	mt	0·5	2·3
H_3O+	nil	0·41	il	2·0	2·4
H_2O-	tr.	0·04	hm	5·7	2·6
P_2O_5	0·50	0·26			
ZrO_2	0·12	0·03	ap	1·34	0·5
Cl'	0·20	0·26			
F'	—	0·07	Z	0·22	0·04
S'	0·06	0·12	nc	0·1	—
SO_3	—	—	hl	0·35	0·4
BaO	0·10	0·035			
SrO	0·07	0·08			
CO_2	0·04	nil			
$(Ce,Yt)_2O_3$	0·02	0·06			
NiO	—	nil			
CoO	—	nil			
Li_2O	nil	n.d.			
Total	99·88	100·04		98·01	98·85
Less O	0·07	0·14			
	99·81	99·90			

A. Pale kenyte 'inclusion' from The Ramp, Cape Evans, Ross Island. K. Chaperlin anal. [D12E].
B. Kenyte from Deviation Hill, Cape Evans, Ross Island. D. I. Bothwell anal. [D70E].

It is perhaps worthy of note that in D12E P_2O_5, ZrO_2, BaO are all twice as high as in the normal kenyte [D70E], but it is clear that nothing short of a microanalysis of separated crystals of the yellow pyroxene will suffice to reveal its composition. In the meantime one may hazard the opinion that the yellow pyroxene in D12E is the same as the mineral described in the yellow variation of the trachytoid phonolites from Observation Hill and Inaccessible Island (p. 33) and that the suggestion made when discussing those rocks is correct, namely that the yellow pyroxene is the greyish-green pyroxene altered.

In these peculiar kenytes the alteration may be due either to reheating of included blocks or to the effect of vapours emanating from the lavas while these were still hot. The change of colour may be due to a change in the state of oxidation of the iron. It will be noted that no H_2O is found in D12E.

The third specimen [D12E*c*] is the one showing the light greyish pink colour to which Debenham's catalogue refers. This contains occasional crystals of the same yellow pyroxene and more numerous micro-insets of iron 'ore' and small apatites as well as the lenticular feldspar insets but the whole of the light grey groundmass is a turbid, devitrified glass showing perlitic cracks (Pl. 5, Fig. 6). There are some oval patches of brown glass and the opaque 'ore' is usually surrounded by a clear, isotropic rim. On the edges of drusy cavities are colourless, birefringent microliths with $c:\gamma=20°$, but in the turbid devitrified glass the abundant colourless microliths have negative elongation. We have no certain clue to the origin of this specimen but it seems to have once had a glassy groundmass. The feldspar insets seem to be free from the characteristic twinning.

A possible clue to the origin of these peculiar types is a specimen collected by Demetri at Land's End, Cape Evans [D59E*c*]. This shows a pale grey, somewhat vesicular, porphyritic kenyte that appears to be an inclusion in a black porphyritic kenyte, pieces of which are adhering to it. The texture of the groundmass resembles that of D12E *a* and *b*, the feldspars being in small spherulitic groups, but there are in the groundmass many patches of colourless glass, much opaque 'ore', some of which is certainly magnetite and some, red by reflected light, may be altered pyroxene. There is abundant apatite, partly associated with the opaque 'ore', but also it appears as crystals at the edges of the numerous druses along with small octahedral crystals of magnetite, and some glass. The feldspar insets have many inclusions and their borders seem to merge with the groundmass feldspar. They show Carlsbad twins and the characteristic cross-hatching of anorthoclase.

In some respects this specimen is similar to sanidinites found as inclusions in kenytes at Cape Royds [1971, 1972] described and figured by J. Allan Thomson* but the biotite he recorded does not appear.

Whether the 'acmite'-bearing specimens [D12E] were inclusions cannot now be determined, but it seems possible that they were, especially as a similar, pale kenyte block, 11 cm. long, was found in normal grey kenyte near the summit of Tent Island by C. S. Wright (Pl. 2, Fig. 1).

A definite inclusion in a weathered mass of kenyte, known to members of the Expedition as 'Antarcticosaurus' [D62E], shows in the hand-specimen abundant patches of blue haüyne. The inclusion contains the typical anorthoclase insets showing cross-hatching and fine-scale twinning. The groundmass is holocrystalline and coarse-grained, the feldspars being in stout, untwinned crystals. The dark minerals, in addition to iron 'ore', are small grains of olivine and some relics of the yellow pyroxene seen in D12E in the process of being resorbed, leaving patches of minute grains of iron 'ore'. The haüyne is abundant in the groundmass and there are also numerous isotropic inclusions in the anorthoclase insets. Small amounts of a rather highly birefringent mineral with high refractive index are present. It is biaxial, positive. It has not been identified.

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* Brit. Ant. Exp. 1907–9, 1916, Geology, vol. 2, 1916, p. 137 and pl. 2, fig. 1.

Another haüyne-bearing inclusion was collected in 'typical kenyte of the northern half' of Tent Island (see p. 14) [D17E]. The texture is similar to the specimen described above except that the haüyne tends rather to form idiomorphic crystals. The feldspar insets in this specimen are plagioclase and the host rock may be a 'basic kenyte'.

Another haüyne-bearing rock was found, apparently in situ, on Inaccessible Island [D14I] but it also is possibly an inclusion for its texture is rather coarse-grained, hypidiomorphic-granular, and resembles that of some sanidinites. Here again there are insets of plagioclase, probably andesine near An_{45}. The groundmass feldspar is in stout crystals with a tendency to rectangular outlines. These show Carlsbad twinning and one crystal showed fine cross-hatching. They are an alkali-feldspar, perhaps anorthoclase. No olivine was observed in the four sections examined. The haüyne occurs as small allotriomorphic patches, not in the well-formed six-sided sections seen in D17E, but it is deeper in colour so that the blue colour is seen even in thin section. Scattered through the feldspar are innumerable, small, colourless inclusions of sodalite (or analcime), and some of these are in places associated with the blue haüyne. Other minerals present are: magnetite, forming small cubic crystals; a greenish pyroxene, non-pleochroic, and with $c{:}\gamma = 54°$; a few flakes and small blades of a pale biotite; and many opaque blades that may be cossyrite. Some parts of the groundmass are confused by the numerous small dark fragments it includes, and the determination of the minerals is difficult.

These haüyne-bearing inclusions do not appear to have been described previously, but Jensen recorded nosean in a 'leucite tephrite' (see p. 77), which, according to him, contains 'inclusions of black magnetite and of honey-yellow to deep brown wöhlerite' (op. cit. p. 112). It is possible that the 'wöhlerite' is the yellow acmitic pyroxene described above.*

Typical of the kenytes with holocrystalline groundmass is D26E from the base of the outcrop at The Slipper, a conspicuous rock to the east of Cape Evans. This closely resembles two of the kenytes described by Jensen from The Skuary, i.e. Cape Evans [J47 and J40].

The hand-specimen is dark olive-grey, only slightly vesicular, holocrystalline with abundant lenticular insets of feldspar averaging about 1·2 cm. in length and occasionally reaching 2 cm.

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* *See also* Woolnough (W. G.), Petrological notes on some of the erratics collected at Cape Royds. Brit. Ant. Exp. 1907–9, Geology, vol. 2, 1916, p. 171 for another record of wöhlerite, but this is quite different from the acmitic pyroxene. It has an extinction angle of 32°. The rock also, a sodalite-syenite, is quite different. A section of this rock [E36] was lent to the author by Sir Raymond Priestley.

The feldspar insets, anorthoclase, all show very fine cross-hatching. Many of them include little fragments of groundmass minerals and, frequently, small crystals of ilmenite or magnetite. Some of the feldspars are simple twins and all show the lenticular cross-sections and habit characteristic of the rhomb-porphyries.

Other insets, all on a smaller scale, are olivine, pyroxene, and small crystals of opaque 'ore'. The pyroxene is quite rare; only 3 small insets (0·25 mm.) were seen in one thin section, as compared with 14 olivines of quite twice the size. The feldspars occupy a very large part of the thin section. Jensen estimated that they constituted about 35 per cent of the rock in J47.

The groundmass of this rock is slightly finer grained than the specimen J47 described and figured by Jensen. The feldspar laths, orthoclase (or anorthoclase), average 0·15 mm. in length, and the majority are less than 0·25. Frequently they are in divergent radial groups. There are abundant pyroxene microliths, pale green to colourless; abundant flakes of a brownish green amphibole; small cubes of opaque 'ore', and interstitial nepheline with apatite needles and some minute sodalites. The feldspar laths show simple Carlsbad twins and give straight extinction. The very small flakes of coloured minerals believed to be alkali-amphiboles are unidentifiable in these fine-grained rocks. In the specimen now described there is a pleochroic brown amphibole, tawny-olive to cinnamon-buff, often with green edges; a deep brown amphibole; and very thin, green flakes that may be aegirine. There are some interstitial patches which are isotropic but have a higher refractive index than feldspar: they were referred to in the general description as glass.

A very similar rock to the above with a slightly higher proportion of opaque 'ore' in the groundmass is the black kenyte collected in situ from a lava-flow under the Barne Glacier [D8E].

This type of groundmass is found in many kenytes but the grain-size varies from the relatively coarse-grained example described to quite fine grain with the feldspar laths averaging about 0·15 mm.

It seems probable from the description of the specimen of which an analysis was made for Jensen that it is rather similar to the rock described above except that Jensen mentions 'some secondary epidote replacing the original aegirine-augite to some extent'. The analysis of the specimen J5 is quoted in column 15, Table III*a*.

D70E from Deviation Hill, E. end of The Trench, Cape Evans, the analysed specimen from Debenham's collection (column 13, Table III*a*), is very similar to D26E described above. Micro-insets are pyroxene, olivine, and an opaque 'ore', and there are abundant large insets of anorthoclase. In the groundmass abundant laths of simply twinned feldspar may be orthoclase. Colourless interstitial areas are partly isotropic and staining tests show that part of the interstitial material is nepheline. The dark minerals comprise small crystal-grains and flakes of pyroxene, a brown amphibole, and opaque 'ore'. The opaque 'ore' seems not to be affected by the acid used to gelatinize the nepheline.

Prior has described and figured* a slightly different type of kenyte from Cape Royds which contains 'in the ground-mass fairly numerous, small, rounded, isotropic crystals of leucite having characteristic central and marginal inclusions of the magnetite and augite of the base' (Pl. 5, Figs. 1 and 2). Similar rocks were described by Jensen, also from Cape Royds [J63], and two of Debenham's specimens from Cape Royds [D6R and D15R], and one from Cape Evans [D1E] are of the same type. These additional specimens do not show the supposed leucites in such abundance as Prior's original specimens [818, 820].

The texture of the groundmass has been described by Jensen as hyalopilitic but some of the rocks of this type have interstitial material that is not glassy but weakly birefringent and appears to consist of nepheline with included sodalite. The feldspar laths are slender and are usually simple twins on Carlsbad or albite laws; nearly all give straight extinction but an angle of 5° was observed. In addition to the laths there are also abundant rectangular sections which should perhaps be regarded as micro-insets. They range up to 0·1 mm. in length. Definite micro-insets of anorthoclase measured were 0·15 mm. across. These small plates have bands of dark inclusions parallel to their edges. Rarely they show fine twin lamellae. Both the rectangular plates and the laths of feldspar have refractive indices just greater than Canada balsam so it is probable that both plates and laths are anorthoclase or potash-oligoclase (in Mountain's sense). Between the feldspar laths is either a pale brown glass with crystallites of pyroxene and magnetite, as in Prior's analysed specimen [818], or lighter coloured, nearly colourless, weakly birefringent material consisting probably of nepheline with included sodalite [820]. In the better crystallized specimens there lie, in this interstitial material, small, colourless prisms of pyroxene, magnetite, and flakes of a brown amphibole, and some aegirine [D15R, D16R]. In a specimen, [D16O] from the moraine of Crater Glacier on Mount Erebus, the interstitial material is brown but not truly isotropic. It seems to be an alteration product of the original minerals.

The 'leucites' described by Prior (see above) are much less abundant in some specimens than in others; indeed in some of the rocks with the same texture and the same kind of feldspars and groundmass as Prior's type-specimens none of the 'leucites' were found. This was the case with two of the rocks from Cape Royds in Debenham's collection [D9 and D10R] and in a small kenyte boulder collected by Demetri on Tent Island [D61E*a*].

The 'leucites' appear in thin sections as approximately circular areas, isotropic and lower in refractive index than the laths of feldspar that lie packed around them. Most of these areas have a cluster of included crystallites of magnetite and pyroxene at the centre but closely packed together and not often showing the arrangement typical of leucite (see also p. 58).

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* Op. cit., 1907, p. 111 and pl. 8, fig. 3.

Such supposed leucites occur in the kenyte with partly glassy groundmass [D10O and D16O] from the moraine at the top of Crater Glacier on Mount Erebus, but much more perfect icositetrahedra, even showing what appear to be lines of inclusions or striae on the faces, are seen in the brown glass of D3R from the Cape Royds district (Pl. 5, Figs. 3 and 4).

Jensen also recorded abundant leucites in some of the kenytes from Mount Erebus and Cape Royds but Lacroix has expressed doubts about Prior's identifications. Prior himself had his doubts as neither the chemical analysis of the rock, nor the partial analysis of the portion soluble in nitric acid, indicated the probability of leucite being one of the constituents. It seems likely that the supposed leucites are either analcime or sodalite, most probably the latter.

The hyalopilitic texture is well shown in D26O (Pl. 4, Fig. 4) from the base of the cliff on the west side of Deep Lake, Cape Barne. The glass is rather more preponderant than in Prior's specimen. The microliths of feldspar are up to 0·35 mm. long. The insets are anorthoclase and augite and micro-insets augite, olivine, and magnetite. Apatite is an accessory mineral and occurs as stout prisms.

Varieties of kenytes, (b) with glassy groundmass

The freshest-looking of the glassy kenyte lavas have a black glass which is lustrous, almost iridescent on the surface in some specimens, though dull in others. The almond-shaped anorthoclase insets are abundant and reach up to 2·5 cm. in width. The glass is slightly vesicular. In thin section it is pale buff, grading to sepia at the edges of the insets and crystallites. It contains feldspar as microliths (0·025 mm.) and minute tabular crystals, grains of augite and magnetite, and many hair-like crystallites. Besides the anorthoclase insets there are micro-insets of olivine and magnetite and very small apatites. The specimen described is D27E from the upper edge of the outcrop of lava at The Slipper, Cape Evans.

A very similar glass with more abundant crystallites and with very slender feldspar microliths nearly hidden by clouds of magnetite particles is D22O from Hooper's Shoulder on Mount Erebus (Pl. 4, Fig. 5). This has pale grey-green pyroxene micro-insets as well as olivine and magnetite. In the hand-specimen the glass is coal-black and vesicular. In thin section it is vinaceous buff to avellaneous. Its refractive index is near to, and slightly greater than, 1·524. This glassy kenyte is very similar to one from Cape Evans (The Skuary) described and figured by Jensen [J25] (op. cit. p. 106, pl. 2, figs. 3 and 4). The specimen of J25 in the British Museum collection shows red patches in the glass, like the streaks and patches in the brown glass described below. In thin section the glass is vinaceous buff in colour. The section is figured in Pl. 5, Fig. 5. Jensen has published a chemical analysis. This is here republished in column 14, Table III*a*.

A rather extreme type with fewer anorthoclase phenocrysts and many small phenocrysts of augite and olivine has the glass, pale olive-buff in colour, almost obscured by masses of long crystallites which generally radiate out from the points and edges of the feldspar microliths. The specimen [D61E*b*] was collected on Tent Island by Demetri.

D3R is similar. The glass is slightly darker, fawn colour, the microliths stouter, and the augite and magnetite rather better developed. Crystallites are less abundant and in the clear glass the little icositetrahedra noticed in some of the brown and yellow glasses are frequent. Some of the stout rectangular microliths might be nepheline. After etching the rock with HCl the solution yielded a small crop of NaCl cubes. This specimen is from the valley above Blacksand Beach, Cape Royds.

A few glassy kenytes show in hand-specimen a black glassy base streaked with thin lines of brick-red colour along flow lines and fissures. One effect of this is that most of the broken surfaces of such specimens are red. Examples are D11E, upper slope of Barne Glacier moraine, and D5T, from the summit of Turk's Head.

Under the microscope the glass in D11E is seen to be very dark brown, opaque in all but the thinnest sections, and veined by very thin bands of yellow glass along fissures and flow planes. The same pale yellowish brown glass is seen making many inclusions in anorthoclase insets. This rock [D11E], is a porphyritic glassy kenyte with small insets, and many broken crystals, of anorthoclase, and micro-insets of olivine, a pale green pyroxene, and apatite. A similar glassy porphyritic kenyte from the summit of Turk's Head [D5T] shows the typical almond-shaped phenocrysts of anorthoclase, and many small, pale yellow olivines. The glass which is dark brown and translucent contains microliths of feldspar and a few minute olivines and augites and is traversed by fissures along which, to a width of 0·09 mm., the glass is decolorized so that it is almost colourless, grading to pale yellow and to chestnut-brown as it merges into the brown unaltered glass at the edges. This rock contains some well-defined crystals with inclusions similar to the supposed leucites described by Prior.

In this connexion it is of interest to note that in a rock [D10O] from the moraine at the top of Crater Glacier on Mount Erebus the glass, which here forms a matrix for close-packed anorthoclase insets, is almost colourless in thin section and is crowded with microliths of feldspar, grains of pyroxene, and magnetite. Very noticeable under a high power objective are numerous icositetrahedra, isotropic, with refractive index less than the glass, and with diameters ranging from 0·008–0·03 mm., sometimes with clusters of inclusions like the leucites (see p. 56).

Prior described several glassy kenytes in which the glass is densely packed with magnetite grains and rods and is thereby rendered quite opaque. In one of his specimens [464] from Tent Island the glass is dark brown and translucent on thin edges but generally opaque with magnetite. In this rock there are streaks of lighter translucent bands of pale brown glass crowded with microliths of feldspar and magnetite dust. In a kenyte [447] from Turtle Back the opaque, glassy base is made up of rough spherulites, dense with magnetite. Between the spherulites small interstices are filled with dark brown glass and feldspar microliths.

In another type [541], from the slopes of Mount Erebus, the glass in the base 'is almost colourless but is rendered nearly opaque with fine dusty magnetite'. The same type is represented in Debenham's collection by D69E, an erratic from High Cliff in the Cape Evans region. The insets in these rocks are the usual anorthoclase with micro-insets of olivine, pyroxene, and apatite. Prior noticed (op. cit., p. 111) that although in the base the glass was dense with magnetite, the glass included in the anorthoclase phenocrysts was clear brown, no magnetite having crystallized out.

Lastly must be described here the remarkable dark brown kenyte-pumice from the recent cinder cone of Mount Erebus of which mention was made in the opening pages of this report (p. 3). At a first glance the masses of this pumice seem to be all glass with no crystals at all but closer inspection reveals crystals of anorthoclase thickly coated with the frothy glass and quite hidden by it (Pl. 2, Fig. 2). These crystals are not very abundant. All those seen belong to type 2 of the crystal habits described by E. D. Mountain,* i.e. they are prismatic crystals with rhombic cross-sections, of which the forms are M($1\bar{1}0$), m(110), and y($\bar{2}01$), either simple crystals or Carlsbad twins with (100) as the composition plane.

The glass in thin flakes is clear and varies in colour from tawny-olive to sepia. Its refractive index like that of the glass of the black glassy kenytes is near and slightly greater than 1·524.

A sample of this glass freed by hand-picking from visible fragments of feldspar was analysed by Mr. J. D. Easton in the Department of Mineralogy, British Museum (Natural History), in 1949. His results are given in column 17, Table III*a*.

A similar pumice holding anorthoclase crystals was found and described by Sir Edgeworth David† at the 'recent' cinder cone of Erebus in 1908 and described by him in the report on the British Antartic Expedition 1907–9, and a sample of this material was analysed by Mr. Burrows and A. B. Walkom with the result given in column 18, Table III*a*.‡

The loose crystals of anorthoclase which strew the slopes of Mount Erebus are doubtless derived from the same source as this brown pumice. Some of them have fragments of vesicular glass still clinging to their faces and some are completely coated by frothy glass. In thin section this glass is pale primrose-yellow and quite isotropic. It is free of microliths but contains a few small crystals of olivine, anorthoclase, and occasional small aggregates of magnetite and apatite.

CHEMICAL COMPOSITION OF THE KENYTES

The analysis of the holocrystalline grey kenyte [D70E] from Deviation Hill, Cape Evans, and that of the brown pumiceous glass from the slopes of Mount Erebus, referred to above, are arranged in Table III*a*. Together with these are: Prior's original analysis of the leucite-kenyte [818], and three others of kenytes from the report of the British Antarctic Expedition 1907–9. For comparison also three analyses of kenyte and kenyte-glass from Mount Kenya have been added (columns 19–21). The corresponding C.I.P.W. norms are given in Table III*b*. In order to facilitate comparisons with some analyses discussed by C. Oftedahl in connexion with his work on the rhomb-porphyries of the Oslo region and their insets and groundmass feldspars the cation (atom) per centage composition and the 'equivalent (or molecular) norms' have also been calculated. For completeness the 'Niggli values', standard norms, 'basis', and Q, L, M, π and γ values have also been given.* These are listed in Tables III*b* to *f*.

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* Mountain (E. D.), Min. Mag., 1925, vol. 20, pp. 331–4, and figs. 3 and 4.

† David (T. W. E.) and Priestley (R. E.), Brit. Ant. Exp., 1907–9, Geology, vol. 1, 1914, p. 213 and pl. 64.

‡ Jensen (H. I.), Brit. Ant. Exp. 1907–9, Geology, vol. 2, 1916, p. 98.

According to the footnote on this page by the editor, Sir Douglas Mawson, 'The pumice analysed is the groundmass of a very beautiful kenyte which forms the latest extravasation of the present active crater of Mount Erebus'.

Leaving out of consideration for the moment the analysis of the glass, it will be noted that for a group of analyses of rocks of the same kind and ranging in silica content only a little over one per cent, 54·9–56·1, there are very marked variations in the percentage of Fe_2O_3 and FeO. The Al_2O_3 shows a range of variation over 1·2 per cent rising with the SiO_2 and the only other notable variation is K_2O which falls with rising SiO_2 from 4·73 to 3·91.

Recalculation of Fe_2O_3 as FeO leads to figures for total FeO which vary only between 5·23 and 6·1, rising with falling SiO_2.

It is worth while to note in passing that this great difference in the distribution of iron, as between Fe_2O_3 and FeO, in rocks otherwise closely similar in composition has an indirect effect on the relative proportion of albite and nepheline in the norm. Fe_2O_3 requires all the available FeO for magnetite under the rules for calculating normative minerals. This means that no $FeSiO_3$ appears in the norm and the SiO_2 that would have been allotted to FeO is available for albite at the expense of nepheline. The result is that, other things being equal, the norm of a rock with high Fe_2O_3 has relatively less nepheline and more albite than the norm for a corresponding rock with lower Fe_2O_3.

A somewhat similar example of kenytes showing wide variation of Fe_2O_3 and FeO in two rocks of nearly the same silica percentage is seen in two rocks from Mount Kenya analysed by G. T. Prior.† In that case, however, the lower Fe_2O_3 is accompanied by much higher Na_2O and some of this appears in the norm as acmite, which utilizes an equal proportion of Fe_2O_3 and requires twice its molecular proportion of silica so that there is not the same effect on the relative proportions of nepheline and albite as would be caused by high Fe_2O_3 unaccompanied by high Na_2O. The above considerations are, of course, equally applicable to the equivalent or molecular norms calculated from cation percentages but not for 'Niggli values'.

Turning now to the analyses of the brown glass of the kenytes the analysis by Burrows and Walkom, column 18, is remarkably close to Prior's analysis of 'leucite-kenyte', column 16, and not far different from the new analysis of D70E, column 13. The important differences would appear to be (1) the reversal of distribution of iron as between FeO and Fe_2O_3 if the glass and D70E are compared and (2) the high Al_2O_3 22·53 and only a trace of MgO in the Burrows and Walkom analysis comparing with 20·79 per cent Al_2O_3 and 1·26 per cent MgO in Prior's kenyte analysis [818], the next highest in Al_2O_3. This may indicate failure to separate MgO from the alumina precipitate in the analysis of the glass. One effect of this in the norm is the appearance of uncombined Al_2O_3 (*C*) and rather low albite and nepheline.

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* *See* Burri (Conrad) and Niggli (Paul), Die jungen Eruptivgesteine des mediterranen Orogens. Erster Haupteil: . . . Berechnungsmethoden. Zürich, 1945, pp. 67 *et seq.*

† Mineralogical Magazine, 1903, vol. 13, p. 247.

The new analysis of the brown glass made on the material collected by Debenham on the Terra Nova Expedition (column 17) shows a lower SiO_2 percentage than the glass analysed for Edgeworth David and Priestley, and this silica percentage is slightly below any of the analysed kenytes. The other particularly noticeable differences are its higher Na_2O and K_2O (8.57 and 4·85) and higher Fe_2O_3 with FeO keeping about the same. In preparing the sample for analysis by Mr Easton care was taken to remove all the visible fragments of feldspar insets, some of which are caught up in this pumiceous glass, so that one expected the analysis to represent the composition of kenyte-glass less the feldspar for the insets. It is almost certain that these insets have approximately the same composition as the loose crystals analysed by E. D. Mountain (see p. 48). If this were so the addition to the composition of the glass of the proper proportion of feldspar of the composition of the insets should result in a composition close to that of D70E or 818.

That this may apply to the feldspathic part of the rocks is indicated by a plot of the normative feldspars on a triangular Or–Ab–An diagram in the manner followed by C. Oftedahl* in his papers on the feldspars of the rhomb-porphyries of the Oslo region. The equivalent (molecular) norms of the feldspars are re-calculated to 100 and plotted in figure 3. It appears from this diagram that the point for the 'potash-oligoclase' of Mountain's analyses (nos. 9 and 10), the normative feldspars in the kenyte D70E (no. 13) and the normative feldspar of the glass from Mount Erebus (no. 17) lie close to a straight line. The same relation is shown more simply in a simple graph on rectangular co-ordinates. 37 per cent of insets of the composition of Mountain's 'potash-oligoclase' and 63 per cent of the normative feldspar of the glass combine to give feldspar Or 39·5 Ab 53 An 7·5, very close to the calculated molecular normative feldspar of D70E, 39:53:8. The same proportion of the glass gives also good agreement for normative nepheline, but the percentage of femic minerals is in poor agreement, the calculated value being far too low.

It is probable that the straight line variation of the feldspar composition is a mere coincidence but it is interesting to note that the same kind of agreement can be found between the analysed anorthoclase of Mount Kenya, a kenyte-glass (phonolite-obsidian), and a kenyte lava from the summit of Mount Höhnel analysed by Prior.

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* Oftedahl (C.), Skrift. Norske Vidensk. Akad. Oslo, I Mat.-Nat. Kl., 1948, No. 3.

It is of more interest to note the very close similarity between the glass of Mount Erebus and the glass from Mount Kenya. The only important differences are the high Na_2O and higher Fe_2O_3 of the Kenya obsidian, which appear as acmite in the norm.

The composition of these glasses, in so far as their normative alkali-feldspars and nepheline are concerned, lies very close to the nepheline-leucite-feldspar point in the

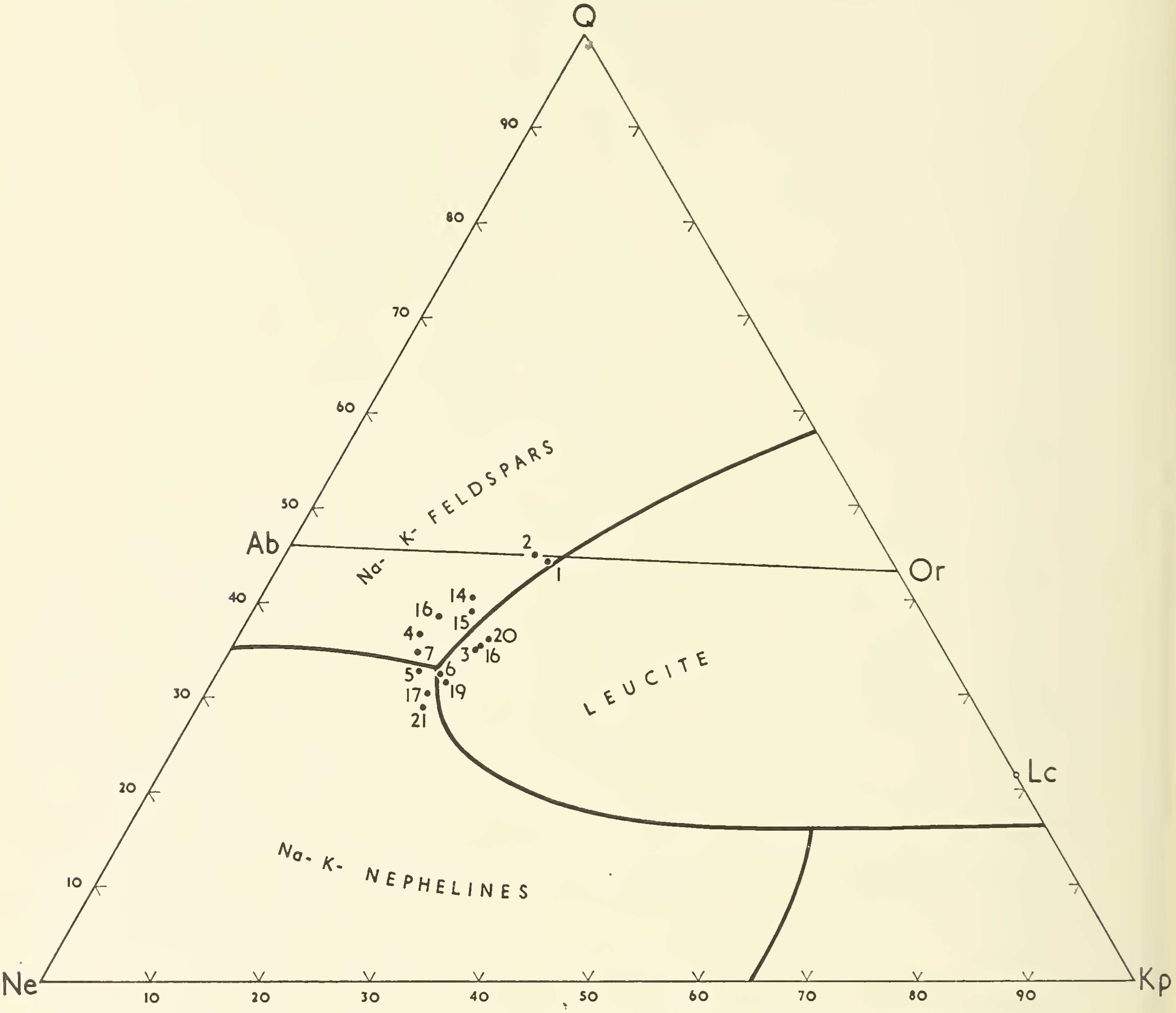

Fig. 4. Kp–Ne–Q triangular diagram showing the fields of crystallization of the primary phases in the ternary system $NaAlSiO_4$–$KAlSiO_4$–SiO_2 and the positions in which analyses of the Trachytoid Phonolites and Kenytes fall on this diagram.

Note. The point close to 3 numbered 16 should read 13. It represents the Kenyte, D70E.

equilibrium diagram for the ternary system $NaAlSiO_4$–$KAlSiO_4$–SiO_2 as worked out by Bowen and Schairer.* In fact they both lie a little on the nepheline side of the ternary point; that is, not quite at the bottom of the low temperature trough as seen in the ternary diagram (Fig. 4).

When the weight per cent norms of the other kenyte analyses are plotted on the same diagram they are seen to follow rather closely the leucite-alkali-feldspar boundary. The points for the two kenytes from Kenya analysed by Prior (nos. 19 and 20) and for the Erebus kenyte [D70E] lie off on the leucite side; the two kenytes analysed for Jensen [J5 and J25] and Prior's leucite-kenyte [818] lie rather further off on the feldspar side. The positions of the Erebus 'potash-oligoclase' and of the Kenya 'anorthoclase' are shown on the same diagram.

As no leucite is recognized in either of the Mount Kenya kenytes or in D70E it seems likely that the alkali-feldspar-leucite boundary surface in a quaternary system, introducing An or Di as a fourth component, may slope off upwards and towards the $KAlSiO_4$ corner. Prior's 'leucite-kenyte' falls so far from the leucite-field as to make the suggestion that the supposed 'leucites' are analcime highly probable.

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* Schairer (J. F.), Journ. Geol., 1950, vol. 58, fig. 1, p. 514.

TABLE III.—CHEMICAL ANALYSES, NORMS, ETC., OF KENYTES

13. Kenyte. I(II).″2.1(2).4., Deviation Hill, east end of The Trench, Cape Evans, Ross Island. D. I. Bothwell, anal. [D70E].
14. Vitrophyric Kenyte, Jensen, 1916. (I)II.5″.(1)2.4. Cape Evans, Ross Island. Hogarth, anal. [J25].
15. Kenyte, Jensen, 1916. (I)II.(5)6.1(2).4. Cape Evans, Ross Island. Hogarth, anal. [J5].
16. 'Leucite-kenyte', Prior, 1907. I(II).5(6).2.4. Cape Royds, Ross Island. G. T. Prior, anal. [818].
17. Kenyte-pumice. ″II.6.1.4. Recent cinder cone of Mount Erebus, Ross Island. J. D. Easton, anal.
18. Pumice, groundmass of kenyte, D. Mawson, 1916. I″.(5)6.2.4. Mount Erebus, Ross Island. Burrows and Walkom, anal.
19. Kenyte. II.6.1.4. From the central core of Mount Kenya. G. T. Prior, anal. [G499].
20. Kenyte. (I)II.′6.1.′4. Lava-flow from summit of Mount Höhnel, Mount Kenya. G. T. Prior, anal. [G462].
21. Phonolite-obsidian (kenyte-glass). II.6.1.4. Campi Sheitani, above the Mackinder Valley (13,000 feet), Mount Kenya. M. H. Hey, anal. [B.M. 1948, 195]. Campbell Smith (W.), Bull. Brit. Mus. (Nat. Hist.), Mineralogy, vol. 1, no. 1, 1950, p. 5.

TABLE III*a*.—CHEMICAL ANALYSES

	13	14	15	16	17	18	19	20	21
SiO_2	54·92	54·84	55·62	56·09	54·17	55·95	53·98	53·80	54·53
TiO_2	1·31	1·34	1·35	1·23	0·73	0·98	0·57	0·31	0·98
Al_2O_3	19·53	18·57	19·07	20·79	19·92	22·53	19·43	18·46	19·48
Fe_2O_3	4·19	6·26	6·06	1·54	2·13	0·99	4·39	6·22	1·18
FeO	1·74	0·47	nil	3·84	4·97	4·54	2·05	0·40	5·72
MnO	0·21	0·21	0·20	0·05	0·26	tr.	0·26	0·33	0·12
MgO	1·07	1·06	1·20	1·26	1·57	tr.	1·07	1·05	1·44
CaO	3·48	3·00	2·72	3·18	2·72	3·21	2·04	2·53	2·28
Na_2O	7·48	6·96	7·56	7·33	8·57	7·42	8·81	7·09	9·16
K_2O	4·73	4·51	4·59	3·91	4·85	3·97	5·27	5·46	4·80
H_2O+	0·41	1·20	0·12	0·39	0·20	nil	1·66	3·54	0·12
H_2O-	0·04	0·62	0·14	0·19	nil	0·09	0·13	0·85	0·06
P_2O_5	0·26	0·85	0·47	0·38	0·06	0·02	0·30	0·53	0·12
ZrO_2	0·03	0·20	0·15		nil				
Cl′	0·26			0·17	tr.	—	n.d.	n.d.	tr.
F′	0·07				0·17				
S′	0·12				0·004				
SO_3	—	0·56	0·97						
BaO	0·035				0·03				
SrO	0·08	abs.	0·28		nil				
CO_2	nil	0·05	0·03		nil		n.d.	n.d.	nil
$(Ce,Yt)_2O_3$	0·06								
NiO	nil	—	abs.		tr.				
CoO	nil				abs.				
	100·04				100·362				
less O	0·14				0·08				
Totals	99·90	100·70	100·53	100·35	100·28*	99·70	99·96	100·57	99·99

* No. 17 total includes PbO 0·006, CuO 0·002, MoO_3 trace.

TABLE III*b*.—C.I.P.W. NORMS

	13	14	15	16	17	18	19	20	21
or	27·8	26·7	27·2	22·8	28·5	23·4	31·14	32·80	28·36
ab	35·1	44·5	44·0	43·0	26·3	40·3	26·46	32·49	23·53
an	6·7	7·2	6·7	12·5	1·5	15·9	—	1·95	—
ne	14·25	6·0	7·4	10·2	25·0	11·9	23·71	15·05	26·90
ac	—	—	—	—	—	—	3·70	—	3·42
di	5·83			0·5	9·7	—	6·64	5·40	8·99
wo	0·93						—	—	—
ol	—	1·8	2·1	5·0	3·85	4·6	0·14	—	6·10
mt	2·3	—	—	2·1	3·1	1·4	4·64	1·62	—
il	2·4	1·5	0·5	2·3	1·4	1·8	1·06	0·61	1·85
ap	0·5	2·0	1·3	1·0	0·1	0·04	0·67	1·34	0·27
hm	2·6	6·2	6·1	—	—		—	5·12	—
ns	—						—	—	0·08
C		0·2	0·4			0·2			
Z	0·04	0·4	0·3						
cc		0·1	tr.						
th		1·0	1·7						
tn		1·4	2·7						
hl	0·4								

TABLE III*c*.—CHEMICAL ANALYSES EXPRESSED AS CATION PER CENT

	13	14	15	16	17	18	19	20	21
SiO_2	50·06	50·86	50·71	50·7	48·3	50·7	49	50·5	48·5
TiO_2	0·87	0·95	0·93	0·81	0·48	0·65	0·4	0·23	0·65
$\frac{1}{2}Al_2O_3$	20·80	20·26	20·40	22·08	20·85	23·9	20·7	20·34	20·37
$\frac{1}{2}Fe_2O_3$	2·87	4·34	4·14	1·06	1·44	0·65	3·0	4·38	0·83
FeO	1·32	0·39	—	2·88	3·7	3·42	1·74	0·60	4·24
MnO	0·16	0·17	0·16		0·2				0·08
MgO	1·45	1·45	1·64	1·74	2·08	—	1·46	1·48	1·92
CaO	3·41	3·01	2·62	3·09	2·58	3·1	2·01	2·55	2·15
$\frac{1}{2}Na_2O$	13·19	12·46	13·31	12·80	14·80	12·94	15·50	12·93	15·8
$\frac{1}{2}K_2O$	5·49	5·34	5·34	4·5	5·57	4·55	5·96	6·55	5·55
$\frac{1}{2}P_2O_5$	0·20	0·67	0·35	0·39	0·04	0·005	0·22	0·45	0·09
ZrO_2	0·12	0·11	0·08						
SrO	tr.		0·16						
Totals	99·84	100·0	99·84	99·98	100·14	99·91	99·99	100·01	100·15

TABLE III*d*.—EQUIVALENT NORMS

	13	14	15	16	17	18	19	20	21
Q	27·45	26·70	2						
Or	27·45	26·70	26·70	22·5	28·35		29·8	32·75	27·75
Ab	37	45·25	42·5	45	25·6		28·9	35·65	24·05
An	5·30	6·15	4·37	12	0·95		—	2·1	—
Ne	17·4	10·23	14·4	11·4	29·04		27·0	17·4	30·0
Wo	4·04	1·32	2·34		4·64		3·26	2·74	4
En	2·90	1·32	2·34	0·6	2·02		2·92	2·74	1·5
Fs	—	—	—		2·62		0·44	—	2·5
Fo	—	1·19	0·70	2·49	1·60		—	0·16	1·76
Fa	—	—	—	2·20	2·09		—	—	2·89
Il	1·74	0·78	0·32	1·62	0·96		0·8	0·5	1·0
Mt	1·53	—	—	1·59	2·16		3·4	1·1	—
Hm	1·85	4·34	4·14	—	—		Ac 3·0	Hm 3·6	Ac 4·0
Ap	0·53	1·79	0·93	0·82	0·1		0·6	1·2	0·24
Pr	0·3								
Zr	0·04	0·22	0·16	—	—				
Ru		0·56	0·77						
Totals	100·08	99·85	99·67	100·2	100·13		100·7	99·94	100·09
Or	39·25	34	36	28·5	51·7		51	46·5	53
Ab	53·1	58	58	56·5	46·5		49	50·5	47
An	7·62	8	6	15	1·7		—	3	—
Q	31·5	35	32·5	34·2	26		27·5	31·8	25·3
Ne	48·3	45·5	48	48·5	53·5		51·5	45·2	54
Kp	20·2	19·5	19·5	17·1	20·5		21	23	20·7

TABLE III*e*.—'NIGGLI VALUES'

	13	14	15	16	17	18	19	20	21
si	172	178·5	180	180	158		165	175	160
al	36	36	36·3	39	34		35	35	34
fm	20	22	21·1	20	24·2		21	22	24
c	11·8	11	9·3	11	8·5		7	9	7
alk	32	31·5	33·2	30	33·2		37	34	35
ti		3·3	3·2				1·3	0·8	2
k	0·29	0·29	0·29	0·26	0·24		0·28	0·33	0·27
mg	0·25	0·23	0·27	0·31	0·21		0·23	0·23	0·26
c/fm	0·59	0·47	0·44	0·54	0·35		0·32	0·39	0·31
qz	−68	−59	−62	−67	−77		−77	−61	−77

TABLE III*f*.—'BASIS'

	13	14	15	16	17	18	19	20	21
Kp	16·55	16	16	13·5	16·5		16·4	18·2	19·7
Ne	39·7	37·5	40	38·4	43·7		44	44	39
Cal	3·35	3·7	2·6	7·25	0·8		Ns 1·2	Ns 1·2	Cal 1·3
Fs	4·3	6·5	6·4	1·5	2·2		1·3	4·6	6·6
Fo	2·2	2·2	1·9	2·6	3·15		2·9	2·2	2·2
Fa	2·25	0·9	0·2	4·3	5·9		6·5	2·6	0·9
Cs	3·2	1·2	2·1	0·3	3·5		3	2·5	2·2
Cp	0·15	[1·7]	0·8	0·8			0·3	0·5	[1·1]
Ru	0·9	0·95	1·0	0·8	0·5		0·6	0·4	0·2
Q	27·5	29·5	28·2	30·4	23·1		23	24	27
Q	27·5	30	29	30·5	23·5		23	24	27·2
L	59·5	58	59	60	61		61·5	62·5	60·5
M	13	12	12	9·5	15·5		15·5	13·6	12·2

IV. BASALTS

All the basalts of the Ross Island Region that have been examined have been found to contain small amounts of feldspathoids in the groundmass. They are slightly undersaturated rocks and are more accurately described as basanitic basalts, or even as basanites.

On the basis mainly of their phenocrysts (insets) and microphenocrysts (micro-insets) one can distinguish several kinds:

1 Basalts with conspicuous tabular insets of plagioclase and micro-insets of olivine.

2 Basalts with insets of augite as well as tabular insets of plagioclase and micro-insets of olivine and magnetite.

These two varieties include most of the rocks included by Jensen with his 'basic kenytes'.

3 Aphanitic olivine-basalts with small insets of augite and olivine.

4 Limburgites with abundant olivine nodules and other xenoliths.

5 The 'hornblende-basalts' of Prior's earlier (1907) report.

6 Some basalts poor in olivine and rich in micro-insets of plagioclase developed particularly at Cape Barne.

Porphyritic Basalts of Mount Erebus and the Dellbridge Islands

The basaltic lavas with conspicuous insets of feldspar—feldspar-phyric basalts—in the collections are almost restricted to Mount Erebus itself. Apart from the rocks called 'basic kenyte' by Jensen there seem to be two types; one with insets of plagioclase, the other with insets of augite in addition to plagioclase. Both have smaller insets or micro-insets of olivine, and the second type has micro-insets of magnetite. The groundmass is similar in the two types and consists of feldspar with augite, subordinate olivine, magnetite, and interstitial colourless material which is probably analcime or nepheline as the groundmass, etched with HCl, gives a solution from which small cubes of NaCl readily crystallize.

The first type is best represented by D10 and D30 from the moraine at the top of Crater Glacier on Mount Erebus (Col moraine of Debenham's notes?) (see p. 5). In hand-specimen the rocks are deep to dark mouse-grey with very numerous spherical vesicles and great numbers of roughly star-shaped groups of thin feldspar plates up to 1·5 cm. across. Some varieties are compact and iron-grey in colour [D20]. In one such rock the groundmass is holocrystalline with intergranular texture and consists of slender laths of plagioclase, grains and prisms of pyroxene (light vinaceous fawn), brown-stained olivine, and cubes of magnetite with interstitial, colourless, weakly birefringent material carrying hair-like crystallites. The plagioclase of the insets is labradorite near An_{60}, and that of the groundmass a slightly less basic labradorite near An_{54}. There are some micro-insets of plagioclase as well as the insets of the stellate groups.

In the glassy variety [D1O] the base is dark brown and almost opaque with a few clear laths of feldspar and micro-insets of olivine. In very thin sections and under high power the base is seen to consist of a colourless material filled with grey crystallites, largely arranged in groups of parallel rods, probably of pyroxene, minute cubes and blades of magnetite and/or ilmenite, and small laths of plagioclase (av. 0·008 mm. across).

D4O, another lava from the moraine above Crater Glacier, is of the same kind as D2O except that the plagioclase insets are not in stellate groups but free and arranged roughly parallel to a plane; also in the base olivine is perhaps more abundant. All the olivine in this rock both in micro-insets and in the base is altered to brown iddingsite. The feldspar insets are labradorite near An_{60} (An_{56}–An_{63}), and the laths in the groundmass give maximum symmetrical extinctions up to 29°, so the composition may be, as for D2O, a labradorite near An_{54}.

Basalt with the conspicuous tabular feldspar insets in star-shaped groups is the common lava of the moraine below Old Fang [D24O] and several examples of it are among the boulders at Lower Fang [D20O], as well as in the moraine at the top of Crater Glacier [D1O, D2O, D3O, D10O, D16O].

Outside the Mount Erebus region the only other examples of this type so far seen in the collections are from Tent Island and from Little Razorback and Inaccessible Island in the Dellbridge group.

D18E, the typical black lava of the summit of Tent Island, has abundant plagioclase insets, tabular parallel to (010) and averaging 0·5 cm. in length.* The groundmass is glassy, consisting of a clear brown glass with microliths of augite, very small magnetite cubes, and laths of plagioclase (mostly 3–4 mm. long). Olivine appears only as micro-insets and not in the glassy groundmass. Other examples are the lava [D47E] bedded above tuff at the SE. end of the island, with numerous plagioclase insets in a black glass, and D42E, a haematite-red porphyritic 'basalt' with a dense, dark brown glassy base from the base of the cliffs on the south side. Mr. Game determined the refractive index as 1·551 corresponding to $Ab_{53}An_{47}$. On Inaccessible Island, D5I, described as 'typical grey kenyte of the northern lower cliffs' is a good example of this type with good insets of plagioclase, micro-insets of olivine, and a holocrystalline groundmass with abundant laths of plagioclase (andesine-labradorite near An_{50}). The plagioclase of the insets is a slightly more basic labradorite near An_{52}.

Jensen described a similar porphyritic 'basalt' from Cape Barne [J49] under his group of 'olivine basalt' (op. cit. p. 115). The hand-specimen shows white tabular feldspars up to 2 cm. across in a dark neutral grey to black aphanitic base. Under the microscope there are seen also rounded micro-insets of olivine, and the base is a brown glass with rods and cubes of iron 'ore' and very small prisms of augite and laths of plagioclase with refractive index greater than balsam. Jensen in his description of the groundmass adds: 'There are also colourless isotropic areas studded with inclusions, and they have probably the composition of nosean or analcite'. In the B.M. section of this rock the isotropic areas are analcime-filled druses and cracks, and in one place the analcime lines a calcite-filled vesicle. The Terra Nova Expedition did not collect this type of lava at Cape Barne (see p. 86).

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* Refractive index determined by Mr P. M. Game, as α' on 001 or 010 = 1·555 corresponding to $Ab_{51}An_{49}$, andesine-labradorite.

Another example of this type with plagioclase insets of two main sizes, the longer 1 cm. and the smaller 2–3 mm. long, in a chocolate aphanitic base [J57 = 1499] is described by Jensen (op. cit. p. 111) and figured (pl. 4, fig. 6) as leucitophyre. His idiomorphic 'leucites and pseudoleucites', however, are nearly spherical vesicles filled with analcime. The base is red-brown glass full of crystallites and with many microliths of plagioclase of higher refractive index than balsam and fewer magnetites and small augites. The specimen is an erratic from Cape Royds and not of great importance, but it seems advisable to mention that the record of 'leucitophyre' among South Victoria Land volcanics is based on an error and is incorrect.*

The second kind of feldspar-phyric basalt, from Mount Erebus, is represented by one specimen from those collected from the moraine at the top of Crater Glacier [D16O] and by many specimens from Lower Fang [D20O].

Primarily these differ from the first type, just described, in that among the insets (and micro-insets) are not only the plagioclase and olivine but also augite.

The augites are larger than the olivines. In colour they are pale purple and the largest extinction angle measured in the sections is $c:\gamma = 43°$. They are feebly pleochroic. An approximately basal section gave, β' pale vinaceous purple, γ' pale vinaceous fawn. The olivines are idiomorphic, up to 1·5 mm. across, and they are colourless with dark alteration products along edges and fissures. There are abundant micro-insets of iron 'ores' (magnetite and ilmenite). The groundmass of the specimen from the moraine at the top of Crater Glacier [D16O] is very fine-grained. It has interstitial colourless material between feldspar laths and augite prisms with brown-stained altered olivine, small cubes of magnetite, and hair-like inclusions in the colourless material. The feldspars of the groundmass appear to be oligoclase-andesine near An_{30}. They give low extinction angles but show simple twins, but some extinction angles up to 13° were observed. The refractive index is near but probably just greater than that of Canada balsam. Good observations of the refractive index were not obtained.

The interstitial material is in places weakly birefringent. Its refractive index is less than balsam so it may in part be alkali-feldspar. The groundmass is, however, etched by HCl and the resultant solution yields a good crop of cubes of NaCl, so nepheline is almost certainly present either as such in the groundmass or as a potential mineral in the interstitial material.

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* The 'leucite tephrite' from the top of Crater Hill, Hut Point Peninsula, also recorded by Jensen (op. cit. p. 111), is also suspect as the chemical analysis by Hogarth, quoted in column 32, table V*a*, shows a low content of potash and the norm calculated from it shows no feldspathoids (Jensen, op. cit. p. 123).

Among the many specimens from Lower Fang one [D20O (33)] shows the plagioclase insets arranged roughly parallel to a plane in the lava. They average $\frac{3}{4}$ cm. in length and are thin and tabular. The black augite insets are fairly numerous but are rarely seen to exceed $\frac{1}{2}$ cm. in diameter. The colour of the groundmass is olive-grey to iron-grey. In some specimens [D20O (34)] the olivines are entirely altered to translucent brown iddingsite. Others [D20O (38 and 39)] are vesicular and have a partly glassy groundmass and carry smaller (1–2 mm.) but more abundant plagioclase insets and micro-insets.

A paler variety (light mouse-grey) [D20O (37)] with abundant plagioclase insets and good idiomorphic augites has more of the colourless interstitial material in the groundmass than the other specimens have. It is clear, in this case, that the material has refractive index less than balsam and, where observed, it proved isotropic. All these specimens give good crops of sodium chloride cubes from the HCl-etch solution.

Here again apart from Mount Erebus itself the only localities at which lavas of this kind have been collected are: Tent Island, Inaccessible Island, and, for this augite-inset type, one can add, Turk's Head, the little promontory SW. of the summit of Erebus and east of Inaccessible Island.

The rock [D46E], described as intruding through tuff on the south-west side of Tent Island, is a good example with very abundant tabular plagioclase insets and with micro-insets of augite and olivine and magnetite in a glassy base.* The glass as seen in thin section is very pale brown and the groundmass consists of this glass with abundant plagioclase laths, augite prisms, and magnetite. Apatite as hexagonal prisms is a frequent accessory. The plagioclase of the insets is andesine near $Ab_{58}An_{42}$. Two of the insets measured are albite-Ala complex twins. Microliths in the glassy groundmass also appear to be andesine near An_{42} but few of the readings obtained were entirely satisfactory.

It is noticeable that the plagioclase insets have rounded ends and a similar habit was observed in the plagioclase insets in D42E, a specimen from the lava forming the base of the cliffs on the south side of the island. The groundmass in this rock is glassy and very dark brown, and the microliths of feldspar are very small. Mr. Game determined the composition of the plagioclase insets as near An_{47}, based on refractive index measurements for α, 1·551. Similar characters are shown by the insets in the 'basic kenyte' described below (p. 75), a specimen collected by Demetri on Tent Island [D61E*d*].

The lava [D39E] from the summit of the island above the gully on the west side seems to be of the same kind with fewer augite insets. It is rich in insets of plagioclase and these average about a centimetre across and are all tabular and have a marked tendency to lie in roughly parallel planes. The groundmass colour is iron-grey. The groundmass reacted for feldspathoids when etched with HCl. Some lapilli in the tuff [D38E] outcropping at the SW. end of the island are of the same kind of lava.

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* The solution obtained after etching the groundmass with HCl yielded abundant cubes of sodium chloride.

On Inaccessible Island the comparable type with insets of plagioclase, augite, and olivine is the rock in situ at the top of East Peak [D30I]. The feldspars of insets and groundmass are plagioclase and the rock resembles D46E from Tent Island, but there are some pale brown veins or patches carrying a yellow mineral like the 'acmite' in the inclusions [D12E, etc.] described above with the kenytes (p. 51). A very good example of a glassy variety of the same type was collected (as a boulder) along with the trachyte of the upper slopes of the island [D27I]. This has a dark brown glassy base in which the feldspar microliths are plagioclase with refractive index quite definitely higher than that of Canada balsam. The groundmass colour is fuscous black and conspicuous in the hand-specimen are bright metallic crystals of magnetite with cubo-octahedral forms giving square and hexagonal (six-sided) sections; they range up to 0·6 or 0·7 mm. across.

At Turk's Head blocks of black glassy porphyritic lava with insets of plagioclase, augite, and olivine, and similar little magnetite crystals occur in the tuff at the summit of the Head. The base in these blocks is a clear pale brown glass [D9T].

Probably this is the glassy equivalent of the lava at the base of Turk's Head [D8T]. This has abundant tabular plagioclase insets up to 3 cm. long and micro-insets of olivine, augite, and magnetite in an aphanitic, deep neutral grey groundmass. The groundmass is holocrystalline and consists of very small colourless prisms of pyroxene and cubes of iron 'ore' in a colourless base of feldspar and isotropic, colourless material of lower index. The feldspar of the insets was found by Mr. Game to be andesine-labradorite, but the groundmass feldspar has very low or straight extinction angles and refractive indices very near Canada balsam. There is a very small amount of a brown amphibole or biotite. Apatite occurs as very small prisms. The solution obtained after etching with HCl gave a very abundant crop of cubes of NaCl, so feldspathoids are evidently abundant in the colourless base.

The groundmass of this rock is clearly more leucocratic and the feldspars less calcic than they are in the 'basalts' described above, though the difference is probably slight. There are probably gradations from one type to the other. Quite similar lavas occur on Inaccessible Island. H. I. Jensen described one of these [J41] as trachydolerite (op. cit. p. 110). It carries very abundant, short, tabular plagioclase insets and micro-insets of olivine, rare augite, and magnetite, in a pale neutral grey groundmass. The insets are plagioclase—Jensen identified them as oligoclase-andesine—and the microliths in the groundmass are also plagioclase but have very low extinction angles and some have straight extinction. There is much other colourless material of low index and some of it is certainly isotropic and may be analcime. Small flakes of brown pleochroic biotite (?) are common in the groundmass.

In Debenham's collection the lava in situ at the summit at the west end of Inaccessible Island [D20I] is exactly similar to Jensen's J41 and this and two similar specimens [D10I and D26I] give an abundant crop of cubes of NaCl from the HCl-etch solution so there seems no doubt that the colourless interstitial material is mainly feldspathoid and not alkali-feldspar. The rocks can be regarded as slightly more leucocratic (tephritic) representatives of the other porphyritic 'basalts' described from Inaccessible Island (p. 72). The plagioclase of the insets in these rocks has been determined on the universal stage by Mr. A. H. Weir. He found them to be: near An_{45} for D20I; An_{42} to An_{44} for D10I; and An_{45} to An_{47} for D26I.

D10I is catalogued as 'typical kenyte from upper part of the island' and D26I is a lava at the base near the couloir. They are neutral grey rocks breaking into flat slabs. They are very rich in the tabular insets of feldspar and, but for the augite, are indistinguishable in hand-specimens from the best examples of the feldspar-phyric 'basalts' [D20O] from Lower Fang on Mount Erebus. There are in fact micro-insets of augite, as well as olivine and magnetite, in D10I.

In addition to his 'trachydolerite' Jensen classified in a separate group some of the lavas with plagioclase insets, calling them 'basic kenytes' on the grounds that the minerals of the groundmass were the same as those of the kenytes. The three rocks in this group described by him in detail do not, however, have these characters. Two of them, J46 from Turk's Head, and J55, an erratic from Cape Royds, have glassy groundmass, and the third, the analysed specimen, J11 from Turk's Head, seems to closely resemble the 'basalts' with tabular insets of plagioclase and micro-insets of olivine of the type described above from Mount Erebus, Turk's Head, and the Dellbridge Islands. Jensen gives a chemical analysis and two figures of this rock (anal. p. 110, and pl. 3, figs. 2 and 3) and claims to have identified 'leucite crystals with characteristic inclusions [and] a few riebeckite grains' in the groundmass (op. cit. p. 108). The duplicate specimen of J11 in the British Museum collection [B.M. 1911, 135, 11] has abundant laths of plagioclase (refractive index greater than Canada balsam) in a brown glass with rather rare augites and small cubes and some blades of magnetite and/or ilmenite. It is thus possible that the British Museum specimen is not a true duplicate of the specimen figured and described by Jensen and analysed. Our hand-specimen has tabular feldspars up to 1·5 cm. long in a dark mouse-grey groundmass. It looks like a slightly more glassy variation of D8T, the lava at the base of Turk's Head, and indeed the specimen is labelled 'Turk's Head, in situ (a flow).', so in all probability that is what it is. The analysis is quoted in column 23, Table IV*a*.

This type of basalt is fairly widespread among the volcanic rocks of alkaline provinces and is known from some of the Atlantic Islands. Examples were described, for instance, by the author from among the basalts of Tristan da Cunha collected by G. Vibert Douglas on the 'Quest' Expedition in 1921.* It was remarked in the report on the expedition that these rocks correspond to Renard's 'felspathic basalts with abundant augite phenocrysts' described from Tristan da Cunha in the Challenger Report.*

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* Smith (W. Campbell), Rep. Geol. Coll. 'Quest' . . . Exp., 1921–1922, 1930, p. 73.

Mr. S. E. Ellis of the Mineral Department, British Museum (Natural History), called my attention to a rock which superficially resembles these Erebus basalts with insets of augite, plagioclase and olivine. This is the rock known to French petrographers as a 'basalte doléritique', or more popularly by Cordier's old name of 'basalte demi-deuil'. It occurs, among other places, as a flow interbedded with 'cinérite' near the Lusclade quarry on the right bank of the Dordogne between Mont Dore and La Bourboule [B.M. 1952, 248(24)]. J. Jung† refers to it as occupying the plateau of the Banne d'Ordanche and he quotes an analysis made for Lacroix by Pisani. In the original paper by Lacroix ‡ there is also an analysis of a glassy variety of the same flow. Lacroix classified it with his 'basaltes téphritiques'. Earlier Auguste Michel-Lévy§ had described the same rock as 'basalte à structure ophitique' and an analysis was made for him by E. Bonjean.|| The ophitic relation of the plagioclase ('bytownite') to augite referred to by Michel-Lévy is not displayed by any of the British Museum specimens [B.M. 54088; 71100; 1952, 248 (24)]. Another example of a rock of the same kind in the British Museum Collection is B.M. 52616, tephritic olivine-basalt from Croix Plateau, Mont Dore.

In spite of what has been written above, it seems that the provision by Jensen in his classification of the rocks of Mount Erebus region for 'basic kenytes' had more justification than the evidence of the duplicates of his described examples would appear to show. Among the weathered blocks in Debenham's collection from the summit of Inaccessible Island one specimen does consist of tabular plagioclase insets in a groundmass like that of some of the kenytes. The tabular shape of the insets is not very marked and the specimen [D251] differs very little in the appearance of the hand-specimen from many of the kenytes. The colour is light neutral grey; it is slightly porous in texture, and the insets are numerous. There are small insets of olivine as well as of feldspar. Under the microscope it is quite clear that the feldspars of the phenocrysts are plagioclase with very thin twin lamellae and sometimes showing very fine twinning like anorthoclase, but the refractive index γ' is very close to 1·556, and α' is greater than 1·550. Such extinction angles as have been measured on the ordinary microscope stage indicate a composition near An_{45}, which is confirmed by the refractive indices. The feldspar is thus determined as andesine, but its potash content remains unknown.

The feldspar laths of the groundmass are simple twins with very low, rather wavy,

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* Renard (A.). Report on the rock specimens collected on oceanic islands during the voyage of H.M.S. *Challenger* during the years 1873–1876. The voyage of H.M.S. *Challenger*, Physics and Chemistry, 1899, Vol. 2, part 7, p. 78.

† Jung (J.), Mem. Carte. Géol. France. Géologie de l'Auvergne . . ., 1946, p. 215 and anal. no. 7, p. 216.

‡ Lacroix (A.), C.R. Acad. Sci., Paris, 1917, vol. 164, p. 585, columns 6 and 7.

§ Michel-Lévy (Aug.), C.R. Acad. Sci., Paris, 1899, vol. 128, p. 1080.

|| Bonjean (E.), ibid. p. 1097.

extinction and refractive index less than balsam, so they may be anorthoclase as in Jensen's basic kenytes.

The other constituents of the groundmass are a pale augite with purple tinge ($c{:}\gamma = 51°$), abundant olivine, and magnetite and colourless interstitial nepheline (confirmed by micro-chemical tests), also very minute flakes of a green, feebly pleochroic aegirine-augite, and a few flakes of a brown pleochroic amphibole, perhaps referable to catophorite. There are also micro-insets of magnetite and apatite. The grain-size of most of the feldspar laths is about 0·35 mm. Mr. A. H. Weir confirmed by measurements on the universal stage that the feldspars are near An_{45}. It is unfortunate that only one specimen of this kind was found on the island and that it was a loose boulder.

A purple-drab 'basic kenyte' is among the specimens collected by Demetri on Tent Island (see p. 14). The other specimens were kenytes and a glassy basalt. The 'basic kenyte' [D61E *d*] has plagioclase insets (andesine, near An_{45}) with definite albite twinning and many show strong zoning. Many of them have broken edges and rounded ends as if they were xenocrysts. The micro-insets in this rock are augite, small magnetites, and olivine associated with apatite (Pl. 4, Fig. 6). The groundmass, extremely fine-grained, looks like a very fine-grained example of the type of groundmass seen in the Cape Royds erratics in which Prior's supposed leucites occur. Good examples of these 'leucites' with their central clot of inclusions are to be seen in Demetri's specimen.

The plagioclase insets in these two rocks may possibly be xenocrysts in the kenyte matrix. A similar suggestion might also be made to explain the appearance of plagioclase insets along with corroded anorthoclase in the glassy kenyte lava [D4T] from Turk's Head, and the same explanation might also hold for the rare plagioclase insets with rounded ends and the insets of purplish augite in the kenyte from Turk's Head summit [D2T].

If this is a correct explanation the 'basic kenytes' are hybrid rocks and the plagioclase must be derived from earlier basaltic lavas.

Kenytes with tabular insets showing fine albite twinning were among the rocks described by J. W. Gregory from Mount Kenya* but in these rocks the plagioclase is potash-oligoclase and its composition is probably not very greatly different from that of the rhomb-shaped insets of the typical kenytes. Commenting briefly on these rocks in 1931 the present author† remarked that they appear to represent transitions from the true kenytes to the trachybasalts. Jensen‡ considered kenytes, 'acid' and 'basic', as groups of the trachydolerite family, but the true kenytes are now known to be definitely phonolites. It is evident that the 'basic kenytes' seen by Jensen had insets of anorthoclase (almond-shaped) as well as tabular oligoclase, and his description of the groundmass of representative examples differs very little from the description of the groundmass of the other kenytes.

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* Gregory (J. W.), Quart. Journ. Geol. Soc., 1900, vol. 56, p. 212, and p. 222, pl. 12, fig. 2.

† Smith (W. Campbell), Quart. Journ. Geol. Soc., 1931, vol. 87, p. 247–8.

‡ Jensen (H. I.), op. cit., p. 103 ;pp. 107 and 108.

BASALTIC LAVAS OF HUT POINT PENINSULA

Olivine-basalts (*Prior*, 1907) *and Limburgite*

Prior, in his report on the rocks collected by H. T. Ferrar during the Discovery Expedition of 1901–4 (op. cit. p. 104), gave a general account of the rocks classified by him as olivine-basalts and provided two analyses. His analysed example [656] from a cliff near The Gap, between Observation Hill and Crater Heights, has numerous small insets of purplish augite and smaller insets of olivine, both equally abundant, in a groundmass of small laths of plagioclase, grains of pale purple-brown augite, magnetite, and a little colourless interstitial material. The augite and olivine are much in excess of the feldspar. The analysis is quoted in column 28, Table V*a*.

Rocks resembling this analysed type of Prior's [656] were collected by Debenham from:

Harbour Heights [D1H]; west corner, Crater Heights [226]; and, a slightly more feldspathic variety, from a mound below Harbour Heights, at a mile from the Hut [260].

In the groundmass of the last-mentioned specimen are microliths of plagioclase, small augites with abundant cubes of magnetite, and interstitial brown glass containing small plates of opaque 'ore' (ilmenite?). The feldspars have symmetrical extinction angles near 25° corresponding to andesine near An_{46}.

Another example of this type, slightly richer in feldspar than the analysed specimen, is No. 383 of the Discovery collection from below Castle Rock near Sulphur Cones, mentioned by Prior as 'accompanying the hornblende-basalts' (op. cit. p. 105).

Prior also gave an analysis of another basalt [326] from Ridge Road, Winter Quarters. This he described as a limburgite-like rock but after reviewing the analysis and comparing it with the analysis of his 'olivine-basalt' [656] he recognized the fact that it only differed by its much more glassy base. As a matter of fact Prior was working with a rather thick section and the groundmass, being dense with magnetite, appears, under a low magnification, to remain dark between crossed nicols. Actually it consists of very abundant magnetite, purple-brown augite, and laths of plagioclase, but it is too dense to show whether interstitial colourless material or glass is present or no. There are in this rock abundant insets and micro-insets, definitely two generations, of olivine and augite. The analysis is quoted in column 29, Table V*a*.

The norms of these analyses [656 and 326] show 12·50 and 11·64 per cent normative nepheline, but this is not expressed as identifiable nepheline in the rock. Etching with HCl, however, produces a solution yielding cubes of sodium chloride on evaporation. The sub-rang of the C.I.P.W. classification, III.6.3.4., in which these analyses fall, includes over 60 basalts all with normative nepheline. In the classification of Lacroix they would be classed as 'basanitöide', but they are referred to here as basalt throughout as Lacroix's name has not been widely used hitherto.*

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* Denaeyer (Marcel, E.), Tableaux de Pétrographie. Paris, 1951, p. 89.

Many of the basalts in the sub-rang, III.6.3.4., are from Atlantic Islands. Among the great numbers of analyses it is difficult to select the best comparisons, but perhaps the closest resemblances are found among the analyses of basalts from Madeira, these, like the Hut Point basalts, showing a rather high TiO_2 content. These rocks were described by C. Gagel.* They had also been classified by Finckh. Examination of Gagel's collection now in the British Museum (Natural History) [B.M., 1923, 604] shows that, while most of the Madeira 'basalts' differ from the fine-grained, dense, basalts of Hut Point, yet it is possible to find some tolerably close matches, e.g. the basalt from Canical listed in Washington's tables as 'limburgitic trachydolerite'† (no. 128, p. 623). The three analyses of Madeira rocks in III.6.3.4. (Washington, nos. 36–38, pp. 680–3) are of rocks not texturally so similar to any of the Hut Point basalts examined.

The rather unusual analysis by Mr. Hogarth of the rock J31 from Crater Hill, Hut Point, described by Jensen as 'leucite tephrite' (see p. 54) resembles the analyses of Prior's two basalts in several constituents, and its values plot fairly near the points for these rocks in the Q–L–M and π–k and γ–mg diagrams (Figs. 6, 7, and 8).

Prior's specimen 326 from Ridge Road can be matched in Debenham's collection by D25H from Point B, between Fortress Rocks and Crater Hill; and, with a more dense groundmass, by D33H, from Fortress Rocks. In these specimens the groundmass contains interstitial vinaceous brown glass in addition to the little augites, feldspar laths, and magnetite (Pl. 6, Fig. 2). An augite inset in D25H gave extinction angle, $c:\gamma' = 55°$. D23H from Boulder Cones is rather similar to D25H. It has many insets of augite and some of olivine in a groundmass with marked flow-structure shown up by streaks of more dense black colour.

In hand-specimens these rocks are aphanitic, compact to slightly vesicular, and deep to dark neutral grey.

Differing from these only slightly are several basalts from Harbour Heights above Hut Point. They contain rather more feldspar, which occurs as short laths showing some tendency to parallel arrangement. In these rocks [D20H, 1 and 4] there are abundant micro-insets of idiomorphic, colourless olivine and only a few, very small, vinaceous buff augites. The groundmass consists of abundant short, thin laths of plagioclase, between which are grains of augite, brown glass with cubes and tiny needles and rods of opaque 'ore' (probably magnetite and ilmenite), and some slightly feathery crystallites. A second generation of smaller olivines and augites is scattered through this groundmass. These are very dense aphanitic basalts. The weathering of the abundant iron 'ore' gives to the general colour a purple-drab tinge.

Other 'basalts' from Harbour Heights [D20H, (3) and (5)] are lighter coloured and somewhat richer in feldspar. These contain abundant micro-insets of olivine, many of them idiomorphic, and only rare small augites. The texture of the groundmass is intergranular. Small prisms and grains of augite and cubes of magnetite with some colourless material, generally birefringent, lie between the very numerous slender feldspar laths (Pl. 6, Fig. 1). The colourless material has low birefringence and may be nepheline. Minute colourless needles in the colourless base are probably apatite.

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* Gagel (C.), Studien über den Aufbau und die Gesteine Madeiras. Zeits. deutschen geol. Gesellschaft, 1912, vol. 64, pp. 429 and 439.

† Washington (H. S.), Chemical analyses of igneous rocks. Washington, 1917.

In a darker coloured variety of this type the olivines have dark brown, almost black, rims due partly to marginal alteration, partly to the way in which magnetite is packed round the insets.

A rock similar to these [J9 = 1918] was collected on the 1907–9 Expedition at Observation Hill, Hut Point Peninsula. It is erroneously listed by Jensen as limburgite (op. cit. p. 116), but nevertheless he correctly describes the rock as consisting of 'hypidiomorphic grains of titaniferous pyroxene (about 50 per cent.), labradorite microlites (about 35 per cent.), idiomorphic magnetite (about 10 per cent.), and olivine in microscopic phenocrysts (about 5 per cent.).'

A true limburgite was collected by Debenham from a lava-flow below the west side of Fortress Rocks, probably derived from Crater Hill. This is a black, aphanitic, slightly vesicular rock with many inclusions, some of which are angular nodules of olivine, while others have quite different characters and are perhaps derived from sedimentary rocks. Under the microscope the rock is seen to consist of a dense black glass with a very few thin laths of plagioclase (labradorite), insets of idiomorphic olivine, and micro-insets of augite, brown hornblende, and olivine*. Prior described a limburgite with large nodules of olivine from Franklin Island in his report on the rock-specimens collected by the 'Southern Cross' Antarctic Expedition†. The glass in this rock is paler in colour than in the Hut Point limburgite and brown hornblende is not present.

H. I. Jensen quotes an analysis of limburgite from Mount Erebus [J68] but there seems to be no published description of the rock in his own memoir nor is its exact locality defined. The analysis has been included with those of the basalts in column 25, Table V*a*. A somewhat similar analysis is that of a basalt from Possession Island in the Crozet Islands, described by R. Reinisch and listed by Washington (op. cit. p. 709).

Another dense black, aphanitic lava with angular inclusions of olivine is D18H, a flow 100 yards NE. of Castle Rock. It has very small micro-insets of olivine and still smaller ones of magnetite in a fine-grained groundmass with vast numbers of minute cubes of magnetite and nearly colourless augite crowded between abundant short thin feldspar laths, which have a roughly parallel alinement. Another specimen bearing the same number and presumably from the same flow is vesicular and has intersertal texture with colourless interstitial glass and the iron 'ore' in blades as well as stouter crystal forms. Many of the vesicles in this specimen are filled with analcime.

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* The basalt from Ridge Road, Winter Quarters, [326] is listed in Washington's Tables as limburgite but see p. 76. Washington (H. S.), Chemical analyses of igneous rocks. Washington, 1917, p. 687, No. 64.

† Prior (G. T.) *in* Report on the collections of Natural History made in the Antarctic Regions during the voyage of the 'Southern Cross'. London, 1902, p. 328.

Another olivine-basalt that needs to be mentioned, though its exact relation to other types described is not clear, is one [261] from Harbour Heights at the highest point before the first crater. This is a fine-grained basalt with intergranular texture. There are small insets and micro-insets of colourless olivine in a groundmass of plagioclase laths, augite, olivine, and magnetite, all well crystallized. The grain-size of the groundmass feldspars and augite is about 0·015 to 0·02 mm. The magnetite is in good small crystals and belongs perhaps to the period of the micro-insets. The particularly interesting point about this rock is that it contains numerous small segregations consisting of slender skeletal purple augites in a colourless base crowded with long rods of iron 'ore' (ilmenite?). This base is partly isotropic and is probably glass or devitrified glass, but there are also in it clear, colourless, weakly birefringent patches of a mineral with refractive index near Canada balsam; this is probably nepheline. There are a few plagioclase laths also in these segregation areas. The patches are irregular in form, may be up to 5 mm. across, and show up in the hand-specimen as dull, dark areas. They probably stand to the 'basalt' in the same relation as the brown hornblende inclusions described by Prior do to the Observation Hill trachytes.*

'Hornblende-basalts' (*Prior*, 1907)

Other lavas from Hut Point Peninsula were described by Prior under the name of 'Hornblende-basalt' (op. cit. p. 102). The analysed specimen [385] from Sulphur Cones is a compact, fine-grained, neutral grey rock with very small (up to 5 mm.) black insets, and very rare insets of feldspar, and small magnetites. The hand-specimen shows one of the coarse-grained gabbro-like nodules described by Prior and further mentioned below. Prior's description of these rocks is as follows: 'Under the microscope small phenocrysts of pale purplish-brown augite and deep reddish-brown basaltic hornblende (or more often magnetite-pseudomorphs after hornblende) are seen in a ground-mass of felspar-laths, magnetite-grains, purplish augite in grains and needles, and small olivines. The felspar-laths are mostly of labradorite, giving symmetrical extinctions in twin lamellae of about 22°. Apatite is plentiful in the ground-mass and as inclusions in the hornblende-pseudomorphs (see Fig. 59); it has often a pinkish tinge and is cloudy with black inclusions arranged in lines parallel to the sides of hexagonal sections.'

The groundmass in the analysed specimen [385] is lighter coloured than in any of the rocks described above under 'olivine-basalt' (Prior). It has colourless material between the feldspars. This has a lower index than plagioclase and is probably nepheline. There are a few small olivines but they are rare. Small augites, as micro-insets, are common and show zoning, and the remarkable coloured apatites noted by Prior are prominent accessories. The pseudomorphs of hornblende consist, as Prior has remarked, principally of magnetite in little crystals and the associated material seems to be pyroxene and perhaps also feldspar. An interesting point, also noted by Prior,* is that these pseudomorphs are rimmed with augite. One can see in the sections many idiomorphic augites with a cloud of magnetite crystals in the middle, and these probably represent the final result of the resorption of hornblende.

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* Prior (G. T.), op. cit., 1907, p. 118.

The rocks grouped by Prior under 'hornblende-basalts' show variations especially in the groundmass. A specimen [391] from Castle Rock, Hut Point, a fine-grained, deep neutral grey rock with a tinge of purple-drab here and there, shows well-marked flow-structure. It carries insets of augite (up to 3 mm.) and of magnetite (1·5 mm.) as well as the abundant pseudomorphs of hornblende. A little of the original brown hornblende remains unaltered. Olivine is absent. This rock carries the remarkable apatites described by Prior. Their colour in thin section is vinaceous buff and crystals measure up to 0·15 mm. across. They are quite abundant especially in some of the hornblende pseudomorphs.

Nothing quite like these rocks happens to have been sectioned from Debenham's collection from Hut Point Peninsula, but a specimen [249] from Half Moon Crater carries abundant brown hornblendes and hornblende pseudomorphs in a streaky, grey and black groundmass with marked flow-structure. This groundmass is very fine-grained and consists of plagioclase, augite, and magnetite. The last is in two sizes; cubes about 0·02 to 0·04 mm., and much smaller ones (0·004 mm.), very abundant. Olivine is present only as rare micro-insets. There are some apatites like those described above but less well developed.

Other rocks collected from Hut Point Peninsula by Debenham showing fresh brown hornblende resemble in other ways the olivine-basalts described above. Such are: D5H, a boulder from the Ski Slope; also [267] from Hut Point, and [227], a lava in situ on the SW. lip of Middle Crater, Point C. These rocks are aphanitic, dusky drab to deep mouse-grey, and they are full of inclusions of olivine, white gabbro-like rocks, and large hornblendes up to 2·5 cm. across. It is noticeable that fresh fractures on these rocks are dark neutral grey but older surfaces are dusky drab. Rather similar rocks, black and glassy on fractures, were collected by Ferrar 'near the ship, Winter Quarters' (i.e. Hut Point) [87171, 335 and 339]. These carry many included nodules of olivine.

Among the Mount Erebus lavas brown hornblende occurs in a glassy, porphyritic basaltic lava from the base of Abbott's Peak [D18O] and from the red-weathered blocks on its summit [D29O]. These rather vesicular lavas carry abundant tabular insets of plagioclase (labradorite, near An_{52}) with many dark glass inclusions. In the brown, glassy groundmass are very abundant laths of plagioclase along with insets of augite, greenish in colour, less abundant olivine, and the brown hornblendes already mentioned.

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* Prior (G. T.), op. cit. 1907, p. 103 and fig. 59. The specimen figured is number 391, not 691 as stated in the caption. The extinction angle, 22°, is too low for labradorite and corresponds to andesine An_{40}.

These rocks are closely related to the porphyritic basalts with insets of plagioclase, augite, and olivine described in the earlier part of this chapter.

The analysis of Prior's hornblende-basalt from Sulphur Cones is given in column 27, Table V*a*. In some respects it is intermediate between the other Hut Point basalts of which analyses are given in the same table, and a rather more leucocratic hornblende-bearing 'basalt' from the foot of Mount Terror described by Prior in his account of the rock-specimens collected by the 'Southern Cross' Expedition.* His analysis of this rock is given in column 24, Table IV*a*. The norm shows notably higher *ab* and lower *di*, *mt*, and *il* than 385 and, judged by its norm, the rock might rank as a tephrite carrying a small proportion of olivine but a deep brown, glassy base masks its relatively felsic character when compared, for instance, with the rock [249] from Half Moon Crater described in the preceding paragraph. It would be called 'téphritoïde' in Lacroix's classification.

Other records of brown hornblende in Ross Island basalts are in specimens (? inclusions) from the 900 foot knoll on Cape Crozier [B.M. 87171 (180)] and in a rock from Cape Bird [P317 (630) = B.M. 1911, 135 (31)] to which Jensen applied the name 'kulaite' (op. cit. p. 124), and two other specimens from Cape Bird [J36(1944) and P325(648)].

The specimen J36 is figured and described by Jensen (op. cit. p. 123 and pl. 3, fig. 6). It contains many pseudomorphs of hornblende with small insets of augite, olivine, and occasional plagioclase and micro-insets of magnetite in a groundmass of plagioclase laths, small augites, and very small magnetites and interstitial glassy base. The enstatite recorded by Jensen in the groundmass was not observed. The analysis of the other specimen [P325 (648)] which is described as similar to J36 is quoted in column 22, Table IV*a*. In some respects it is not very different from that of 87572 (93), Prior's analysed 'hornblende-basalt' from Mount Terror.

In general the basalts collected by Ferrar at Cape Crozier, as well as those collected by Dr. Wilson from the cliffs (Crozier Cliffs), which show the good columnar structure, [830] all resemble the basalts of Hut Point. The resemblance extends to the appearance in some of them of brown hornblende (see above).

The same may be said of the rocks from Cape Bird collected on Shackleton's expedition and variously described by Jensen as 'olivine basanite', 'alkaline dolerite', and 'limburgitic dolerite' (op. cit. p. 125).

The nearly colourless pyroxene of the micro-insets of the 'limburgitic dolerite' [P322 (642)] was referred by Jensen to enstatite, but this identification seems doubtful. Crystals measured on the duplicate specimen [BM. 1911, 135 (43)] give extinction $c{:}\gamma$ up to 47°, but birefringence is rather low.

The 'olivine basanite' [P334 (654)] is interesting as it contains some rounded xenoliths one of which may well be quartz surrounded by a turbid reaction rim. Others show

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* Prior (G. T.), Report on the collections of Natural History made in the Antarctic Regions during the voyage of the 'Southern Cross'. London, 1902, p. 326.

TABLE IV.—CHEMICAL ANALYSES, NORMS, ETC., OF 'BASIC KENYTE' AND HORNBLENDE-BASALT

22. 'Kulaitic Basalt', Jensen, 1916. II.5″.3(4).4.
Cape Bird, Ross Island. Burrows and Walkom, anal.
[P325(648)]. Jensen, 1916, column viii, p. 122, and p. 124.

23. 'Basic Kenyte, Plagioclase Kenyte', Jensen, 1916. II.″6.″3.4.
Turk's Head, Ross Island. Hogarth, anal.
[J11(1920)]. Jensen, 1916, column vii, p. 122, and p. 108.

24. Hornblende-basalt, Prior, 1902. II.6.(2)3.4.
Foot of Mount Terror, Ross Island. G. T. Prior, anal.
[B.M.85752(93)]. Washington, 1917, p. 577, no. 22.

TABLE IV*a*.—CHEMICAL ANALYSES

	22	23	24
SiO_2	48·26	47·56	47·40
TiO_2	0·88	2·60	0·63
Al_2O_3	22·67	18·77	20·27
Fe_2O_3	3·22	1·66	5·38
FeO	4·56	7·13	5·48
MnO	0·11	0·20	0·17
MgO	3·73	2·82	2·94
CaO	8·68	7·82	7·59
Na_2O	4·03	5·15	5·78
K_2O	2·15	2·68	2·73
H_2O+	0·32	1·27	0·23
H_2O-	1·01	0·82	ig.
P_2O_5	tr.	0·07	0·85
CO_2		tr.	
ZrO_2			
SO_3		0·06	
SrO		0·21	
	99·92	98·82 *	99·45

* Low summation.

TABLE IV*b*.—C.I.P.W. NORMS

	22	23	24
or	12·51	16·01	16·12
ab	23·06	20·07	20·96
an	37·25	20·02	20·29
ne	5·96	12·70	15·34
di	4·70	15·08	9·06
ol	8·35	4·15	5·63
mt	4·64	2·46	7·89
il	1·67	5·02	1·22
ap		0·17	2·02
pr		0·05	

TABLE IV*c*.—CATION PER CENT

	22	23	24
SiO_2	45·4	44·5	44
TiO_2	0·6	1·8	0·4
$\frac{1}{2}Al_2O_3$	25	21·8	22
$\frac{1}{2}Fe_2O_3$	2·25	1·2	3·8
FeO MnO	3·65	5·7	4·3
MgO	5·25	3·9	4·1
CaO	8·75	7·9	7·5
$\frac{1}{2}Na_2O$	7·35	9·3	10·4
$\frac{1}{2}K_2O$	2·5	3·2	3·2
$\frac{1}{2}P_2O_5$		0·6	0·3
	100·75	99·9	100·0

TABLE IV*d*.—EQUIVALENT NORMS

	22	23	24
Or	12·5	16·25	16·0
Ab	25	23	21
An	38·5	23	21
Ne	7	14·1	18·6
Wo	2·1	4·6	5·6
En	1·5	2·6	3·8
Fs	0·6	2·0	1·8
Fo	6·7	3·9	3·3
Fa	2·5	3·4	1·65
Il	1·2	3·7	0·8
Mt	1·8	1·8	5·7
Ap	tr.	1·5	0·8

TABLE IV*e*.—'NIGGLI VALUES'

	22	23	24
si	122	126	116
al	33·4	29	29·5
fm	30	31	32·5
c	23·4	22	20
alk	13·2	18	18
ti	1·7	5·2	1·2
k	0·25	0·26	0·24
mg	0·47	0·57	0·34
c/fm	0·78	0·74	0·61
qz	– 91·4	– 79	– 90·5
p	tr.	0·1	0·88
π	0·43	0·27	0·23
γ	0·093	0·22	0·16

TABLE IV*f*.—'BASIS'

	22	23	24
Cp		1	1·7
Ru	0·6	1·8	0·4
Kp	7·6	9·4	9·6
Ne	22	28	31·2
Cal	22·2	13·8	12·6
Cs	1·7	4·7	3·5
Fo	7·7	5·9	6·1
Fa	5·5	9·1	6·5
Fs	3·4	1·8	5·6
Q	29·5	24·8	23·3
Q	29	25	23·5
L	52	51·5	54
M	19	23·5	22·5

TABLE V.—CHEMICAL ANALYSES, NORMS, ETC. OF BASALTS

25. 'Limburgite', Jensen, 1916. ″IV.1(2).2.(2)3.2.
Mount Erebus, Ross Island. Burrows and Walkom, anal.
[J68]. Jensen, 1916, column B, p. 114.
26. Basalt poor in olivine, Jensen, 1916. (II)III.5.3.4.
Cape Barne, Ross Island. Hogarth, anal.
[J4(1914)]. Jensen, 1916, column D, p. 114 and p. 112.
27. Hornblende-basalt, Prior, 1907. (II)III.6.″3.4.
Sulphur Cones, Hut Point Peninsula, Ross Island. G. T. Prior, anal.
[B.M.87171(385)]. Washington, 1917, p. 685, no. 62.
28. Olivine-basalt, Prior, 1907. III.6.3.4.
The Gap, between Observation Hill and Crater Heights, Hut Point Peninsula, Ross Island. G. T. Prior, anal. [B.M.87171(656)]. Washington, 1917, p. 685, no. 63.
29. Olivine-basalt. 'Limburgite-like basalt', Prior, 1907. Limburgite, in Washington's Tables, 1917. III.6.3.4. Ridge Road, Winter Quarters, Hut Point Peninsula, Ross Island, G. T. Prior anal.
[B.M.87171(326)]. Washington, 1917, p. 687, no. 64.
30. Olivine-basalt. III.″6.3.″.4.
Cheyenne Crater, Taylor Valley, Ferrar Glacier region, South Victoria Land. N. E. Butcher and D. I. Bothwell, anal. [D8F].
31. Olivine-basalt. III″6.3.4.
Lava-flow, Black Hill, Taylor Valley, Ferrar Glacier region, South Victoria Land. D. I. Bothwell, anal. [D2F].
32. 'Leucite Tephrite', Jensen, 1916. III.5.(3)4.4.
Top of Crater Hill, Hut Point Peninsula, Ross Island. Hogarth, anal.
[J31]. Jensen, 1916, column xi, p. 122, and p. 111.

TABLE V*a*.—CHEMICAL ANALYSES

	25	26	27	28	29	30	31	32
SiO_2	45·63	43·54	43·92	42·14	42·10	42·92	41·47	41·64
TiO_2	2·42	5·03	4·19	4·90	4·93	3·77	5·19	4·36
Al_2O_3	10·43	16·08	17·42	14·95	14·87	15·34	14·31	13·80
Fe_2O_3	1·20	2·63	4·09	2·90	3·26	3·71	3·96	7·93
FeO	8·93	10·14	8·83	9·71	9·76	10·39	11·48	5·41
MnO	0·17	0·20	0·09	0·12	0·07	0·23	0·22	0·19
MgO	15·01	6·44	4·89	9·47	8·88	7·25	7·07	8·78
CaO	12·89	8·09	9·53	10·32	10·63	10·98	10·03	11·16
Na_2O	2·04	3·61	4·60	3·27	3·20	3·15	3·13	2·14
K_2O	0·74	1·67	2·17	1·80	1·80	1·30	1·59	1·40
H_2O+	0·16	0·36	0·11	0·16	0·12	0·35	0·57	0·47
H_2O-	0·21	0·08	0·06	0·12	0·11	nil	0·36	0·62
P_2O_5	0·43	1·29	0·67	0·40	0·58	tr.	0·49	0·96
CO_2	0·12	0·15				0·08		0·05
ZrO_2						0·03	0·005	abs.
SrO		1·46				0·06	0·08	
BaO						0·057	0·04	
	100·38	100·77	100·57	100·26	100·31	99·9*	101·12†	100·61‡

* Includes S″ 0·10, Cl 0·10, F′ 0·20, also heavy metals.
† Includes S″ 0·27, Cl 0·14, P″ 0·11.
‡ Includes SO_3 1.70.

TABLE V*b*.—C.I.P.W. NORMS

	25	26	27	28	29	30	31	32
or	4·34	9·84	12·79	10·56	10·56	7·78	9·45	8·34
ab	8·07	22·11	11·26	4·72	5·76	9·96	10·84	15·30
an	17·16	23·74	20·57	20·85	20·85	24·57	20·69	23·80
ne	4·94	3·53	14·91	12·50	11·64	8·24	7·98	1·48
hl						0·12		
di	34·34	10·14	17·73	21·99	22·46	23·10	20·61	19·78
ol	23·35	14·29	6·93	14·97	13·44	12·23	12·24	8·96
mt	1·86	3·79	6·03	4·18	4·64	5·36	5·71	2·97
il	4·60	9·63	7·90	9·27	9·42	7·20	9·88	8·29
pr						0·36	0·88	1·26
ap	1·0	2·85	1·68	1·01	1·34			2·22
Z						0·04		—
nc						0·11		
cc	0·26	0·35						
F						0·39		
hm	—	—	—	—	—	—	—	5·84

TABLE V*c*.—CHEMICAL ANALYSES EXPRESSED AS CATION PER CENT

	25	26	27	28	29	30	31	32
SiO_2	41·5	41	40·7	39	39·3	40·5	39·6	39·7
TiO_2	1·65	3·5	2·9	3·4	3·5	2·65	3·7	3·15
$\frac{1}{2}Al_2O_3$	11·2	18	19	16·3	16·7	17	16	15·6
$\frac{1}{2}Fe_2O_3$	0·9	1·9	2·9	2	2·2	2·6	2·82	5·7
FeO MnO	6·85	8·0	6·8	7·6	7·65	8·35	9·35	4·5
MgO	20·5	9	6·8	13·2	12·4	10·6	10·18	12·6
CaO	12·6	9	9·4	10·2	10·6	11·05	10·28	11·5
$\frac{1}{2}Na_2O$	3·6	6·5	8·2	5·9	5·8	5·75	5·8	4·0
$\frac{1}{2}K_2O$	0·85	2	2·55	2·1	2·1	1·60	1·94	1·7
$\frac{1}{2}P_2O_5$	0·36	1	0·55	0·3	0·45	0·1	0·4	0·8
	100·01	99·9	99·8	100·0	100·7	100·20	100·13	99·25

TABLE V*d*.—EQUIVALENT NORMS

	25	26	27	28	29	30	31	32
Or	4·25	10	12·75	10·5	10·5	8·0	9·7	8·5
Ab	8·75	22	13·5	4·75	6·25	9·3	11	16·5
An	19·4	23·6	20·6	20·75	22	24·0	20·75	24·75
Ne	5·55	6·3	16·5	14·85	13·65	11·67	11	2·1
Wo	15·6	5·2	8·8	11·2	10·9	12·10	10·8	10·42
En	12·9	3·7	6·4	9	9·5	8·54	7·6	10·42
Fs	2·7	1·5	2·4	2·2	1·4	3·56	3·2	—
Fo	20·4	10·8	5·4	13·05	11·475	9·49	9·5	11·1
Fa	5·1	4·35	1·7	3·15	3·525	3·93	3·9	—
Il	3·3	7·0	5·8	6·8	7·0	5·3	7·4	6·3
Mt	1·35	2·85	4·35	3	3·3	3·9	4·23	4·05
Hm								3·0
Ap	1·0	2·67	1·5	0·8	1·2	0·27	1·2	2·1
	100·27	99·97	99·7	100·05	100·7	100·06	100·18	99·24

TABLE V*e*.—'NIGGLI VALUES'

	25	26	27	28	29	30	31	32
si	87	100	100	86	87	91	89·1	89·3
al	11·7	21·6	23·2	18	18	19	18	17·4
fm	57·5	46·2	40·5	50	49·5	48	50	51
c	26·4	21·75	23·2	23	23·5	25	23	25·8
alk	4·6	10·4	13·2	9	9	8	8·7	6·3
ti	0·34	0·86	0·18	0·75	0·8	0·6	0·84	0·73
k	0·19	0·23	0·23	0·26	0·27	0·21	0·25	0·30
mg	0·75	0·48	0·41	0·57	0·55	0·48	0·46	0·55
c/fm	0·46	0·47	0·57	0·46	0·475	0·51	0·46	0·51
qz	– 53	– 75	– 83	– 77	– 76	– 66	– 74	– 69
p	0·03	0·01	0·02	0·04	0·05	—	0·05	0·08
π	0·44	0·35	0·27	0·343	0·345	0·395	0·315	0·47
γ	0·27	0·13	0·225	0·194	0·20	0·227	0·196	0·188

TABLE V*f*.—'BASIS'

	25	26	27	28	29	30	31	32
Cp	0·9	2·5	1·5	0·8	1·1	tr.	1·4	1·84
Ru	1·6	3·55	2·9	3·3	3·45	2·65	3·7	3·16
Kp	2·5	6·45	7·7	6·3	6·35	4·75	5·8	5·2
Ne	10·3	19·7	24·6	17·5	17·4	17·4	17·4	12·0
Cal	10	13·95	12·0	12·4	12·55	14·5	12·4	15·4
Cs	15·5	4·25	7·2	8·2	8·5	9·3	8·15	8·1
Fo	30·5	13·6	10·2	19·8	18·6	15·4	15·2	19·0
Fa	10·3	12·2	10·3	11·2	11·4	12·4	14·0	6·75
Fs	1·3	2·8	4·3	3·0	3·35	3·9	4·23	9·2
Q	18·25	21·5	20·0	16·7	17·3	19·4	18·0	20·2
Q	19	22	20	17	17·5	19	18	20·5
L	23	41	45	37	36·7	37	36	33
M	58	37	35	46	45·9	44	46	46·5

isotropic material (? glass) with birefringent grains and one bordered by more highly birefringent material.* These were identified by Jensen as: 'rounded and corroded nepheline phenocrysts and patchy masses of cancrinite after nepheline' (op. cit. p. 125).

BASALTS OF CAPE BARNE

One type of basalt from Cape Barne has been mentioned above (p. 69). The others seem to group themselves into two types, one with a very dense, fine-grained groundmass; the other better crystallized and, as regards groundmass minerals, more coarse-grained than any of the lavas described with the exception of some of the kenytes. They are deep neutral grey, rather vesicular, and show a sheen from small feldspar cleavages on broken surfaces.

Debenham collected this type from Middle Dome, Cape Barne [D24R]. The texture is strongly suggestive of a dike phase, rather than a lava (Pl. 6, Fig. 3). Jensen has given descriptions of two rocks from Cape Barne which both seem, to the present author, to belong to the coarser grained type. One is described under 'basalts poor in olivine' [J2 (1912)] and is figured (Jensen, op. cit. pl. 5, fig. 3). It has small insets of plagioclase and micro-insets of augite and plagioclase as well as olivine (up to 0·4 mm.). Jensen estimated the olivine at 2 per cent.

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* Compare inclusions in the limburgite from Fortress Rocks, Hut Point (p. 78), and in the basalt [D2F] from the Taylor Valley on the mainland (p. 89).

There is a tendency towards parallel alinement of the groundmass feldspars. The texture is intergranular and the groundmass consists of the plagioclase laths with augite prisms, cubes of magnetite, and interstitial glass. There are some rounded patches of glass (?) with many blades of opaque ilmenite (?). The plagioclase, determined by Jensen as labradorite, was estimated by him at 50 per cent of the rock, the other constituents being: 'Faint brown augite and brown glass, 40 per cent. Magnetite, 7 per cent. Olivine, 2 per cent. Apatite 1 per cent'. The plagioclase has extinction angles similar to those of the feldspar in J4 (see below).

A similar rock is J24 [=1933] also described by Jensen (op. cit. p. 113). In this he found the insets to be 'basic labradorite' and he described the groundmass as: 'intersertal, almost panidiomorphic hypocrystalline, consisting of felspar in needles, augite prisms, magnetite grains and apatite in stout rods, with a trace of interstitial glass'.

The third basalt of this type described by Jensen from Cape Barne is J6 [=1915], classified as 'intersertal augite andesite'. In this he found that 'The phenocrysts consist of oligoclase, but the smaller laths seem to be anorthoclase, . . .'. The other minerals were described as 'idiomorphic magnetite grains, a few stray olivines, hypidiomorphic grains and rods of brown titaniferous augite and interstitial glass' (op. cit. p. 112). The identification of the feldspar in this rock seems to be an error. In the duplicate specimen in the British Museum collection the feldspars are andesine, An_{48}, and, in fact, in a very similar rock [J2], described above, Jensen himself identified the feldspars as labradorite. The groundmass consists of laths of plagioclase with idiomorphic magnetites, small augites and olivines, and colourless glass with hair-like crystallites.

The other type with the finer grained, dense groundmass appears to provide a link with the olivine-basalts of Hut Point Peninsula. Examples are described by Jensen under 'basalts poor in olivine' [J4 and J20] and under 'magnetite-basalt' [J22]. J4 has been analysed and the analysis, quoted in column 26, Table V*a*, compares fairly closely with some of the other basalts analysed by Prior except for a remarkably high figure for SrO, 1·46 per cent. There is nothing in the constituent minerals to account for this.

The rock [J4] is a fine-grained olivine-basalt with micro-insets of olivine, and smaller ones of magnetite, and laths of plagioclase in a groundmass of plagioclase, augite, and iron 'ore' in both cubic and platy forms. The texture is intergranular. The feldspars in the groundmass and the slightly larger laths are labradorite. Symmetrical extinction angles range around 26° but a value as high as 39° was observed.

The rock [J22 (1931)] described by Jensen as 'magnetite-basalt' (op. cit. p. 117) has a fine-grained, dense groundmass that is almost opaque under low magnifications, but otherwise the rock does not differ markedly from J20 which Jensen described with J4 and other 'basalts poor in olivine'. Debenham's specimen from The Pyramid (or The Pillar) [D28O] is intermediate in texture between the two types described (Pl. 6, Fig. 4).

All these Cape Barne lavas seem very closely related. As regards their relations with lavas from other localities in the neighbourhood reference has been made to their slight resemblance to some Hut Point basalts. The only other lavas which are probably related to them are some from Little Razorback and possibly also from Tent Island in the Dellbridge group.

The lavas from Little Razorback [D33, 34 and 35E] have many small insets and micro-insets of plagioclase but also some small insets of augite as well as micro-insets of olivine, with very small pyroxenes and magnetites in a glassy base [D35E], or a very fine, opaque base rich in magnetite [D34E]. The groundmass etched with HCl gives a solution yielding cubes of sodium chloride and one supposes potential nepheline to be present in the glass.* The feldspar of the insets was determined by Mr. P. M. Game as andesine-labradorite near An_{52} on the basis of a refractive index for α' of 1·556.

Some of the boulders collected at the NW. end of Tent Island [e.g. D43E] also have many small insets† and laths of plagioclase and seem somewhat similar to the Cape Barne basalts, but these were not found in situ.

Basalts of the Mainland opposite Ross Island

The field occurrence of the basalts that were discovered at a few localities on the mainland opposite Ross Island has been briefly recorded in the opening chapter on the distribution of volcanic rocks in the Ross Archipelago (p. 18). Although these basalts occur outside the geographical area of the Archipelago it seems highly desirable that they should be described here in the same chapter as the basalts of the Hut Point Peninsula to which, as will be seen, they are closely related in time and in composition.

The lavas collected from the flow beside the Howchin Glacier [D3K, D5K] and from the moraine opposite Heald Island in the Koettlitz Glacier valley [D9K] are neutral grey olivine-basalt, with insets of olivine and augite. They resemble rather closely the olivine-basalt [D1H] from Harbour Heights, Hut Point. Some of the olivine is very fresh, bright green, and transparent. The insets of olivine and augite range up to 5 mm. across. There are abundant micro-insets of plagioclase and the fine-grained groundmass consists of minute laths of plagioclase, prisms of augite, magnetite and interstitial glass. Several of the specimens [D5K] contain inclusions of white Beacon Sandstone caught up in the lava and converted to slaggy material at the edges. A coarse-grained, pinkish and vesicular inclusion is probably the result of more complete digestion of the xenolith.

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* This rock and D24R from Cape Barne have now been analysed (see p. 99).

† Mr. Game found the feldspar insets in this rock to be andesine near An_{40}, basing this on a very approximate determination of α' as 1·548.

The lavas from the Cheyenne Crater [D8F, D16F] are represented by several specimens of reddened scoria, vesicular dark grey basalts, and compact, dusky neutral grey basalts with insets of fresh, transparent, green olivine and carrying inclusions of other rocks. One of these inclusions, about 3 cm. across, is of dolerite. It is of the same type as the dolerites that form extensive sills in the Beacon Sandstone Formation.* They are actually seen in situ in the hill capped by the basalt [D2F] on the opposite side of the glacier.

The lavas are similar to some of those from Hut Point Peninsula and to those described above from the Koettlitz Glacier valley. Micro-insets of olivine and augite, and less abundant micro-insets of plagioclase, lie in a fine-grained groundmass of augite, and plagioclase with magnetite and some interstitial colourless glass (Pl. 6, Fig. 5). In some of the specimens, particularly in a black aphanitic basalt [D8F] with occasional small white inclusions, plagioclase decreases in amount and the rock approaches very closely to a true limburgite as is also the case with some of the basalts in the Hut Point Peninsula (p. 78).

The specimens from the lava-flow on the opposite side of the glacier, 'Black Hill' of Debenham's catalogue, are similar to the compact lavas from Cheyenne Crater. They are compact, black, aphanitic with very few visible insets but containing some small, irregular, white patches. These prove to be included fragments of quartz, doubtless derived from the underlying sandstones. Thin sections of the rocks reveal also minute fragments of dolerite similar to the large inclusions found in the basalts at the crater. The quartz xenoliths have a narrow reaction rim of lower refractive index than the quartz [D2F (41)].

In another specimen from this lava-flow [D2F] there are inclusions of opaque black fragments, polygonal in outline, and all bordered by a continuous rim of augite similar to the augite which forms the micro-insets in this rock. These inclusions do not have the shape of hornblende xenocrysts but the border of augite suggests that that is what they might have been (see p. 80).

In this specimen olivine micro-insets are more plentiful than those of augite. One of the augites, light purplish vinaceous in colour, has a core of pale green but is not sensibly pleochroic. The whole crystal, cut approximately parallel to 010, extinguishes uniformly at $50\frac{1}{2}°$ ($c{:}\gamma$). The groundmass is a well-crystallized aggregate of feldspar, augite (laths and prisms), magnetite, and a small amount of interstitial isotropic glass (Pl. 6, Fig. 6). Similar basalts were collected by Debenham on Hut Point Peninsula; for instance, from Harbour Heights [253 and 260], and Crater Heights [226].

Ferrar's specimen [718] from the scree-slope below Cathedral Rocks (see p. 18) compares fairly well with the specimens from Cheyenne Crater and 'Black Hills' described above. In thin section the groundmass appears less dark and the olivine micro-insets are fewer and less well formed. The augite insets in Ferrar's specimen often have included central patches of groundmass minerals. Similar inclusions are seen in D16F from Cheyenne Crater.

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* Smith (W. Campbell), Brit. Ant. (Terra Nova) Exp., 1910. Nat. Hist. Rep., Geol. vol. 1, No. 6, 1914, p. 198.

Prior (op. cit. p. 106) described the rock under olivine-basalts but he: 'distinguished in the ground-mass small colourless patches of isotropic analcite (?), and of doubly-refractive nepheline of which the refraction was about the same as that of Canada balsam', and he added: 'This rock, which showed under the microscope small phenocrysts of pale-purple augite and rounded olivines in a ground-mass of felspar-laths, augite and magnetite, has a much closer relationship to the recent basalts of the Ross Archipelago than to the dolerites of the Ferrar Glacier'.

Specimens from both the localities in the Ferrar Glacier region, Cheyenne Crater and 'Black Hill' were analysed in the Department of Mineralogy, British Museum (Natural History) by Mr. N. E. Butcher and Mr. D. I. Bothwell. Their results are given in columns 30 and 31, Table V*a*. They confirm the close resemblance between these basalts from the mainland and some of those from Hut Point Peninsula on Ross Island.

Thus, in the Q–L–M diagram (Fig. 6), their points fall very near those for the Hut Point basalts analysed by Prior [656 and 326], and the values for k and for γ are the same for Prior's two analyses and for D2F and they are not very different for D8F.

V. SUMMARY AND CONCLUDING REMARKS

This account of the volcanic rocks of the Ross Archipelago has been compiled from the notes provided with the specimens, from the field catalogues, and from the published accounts of the physiography of the region by Professor Frank Debenham and by other members of the Expedition.

The rocks have been described under three main headings: phonolitic trachytes and trachytoid phonolites; kenytes; and basalts.

The first group includes a phonolitic trachyte restricted, so far as is known, to Mount Cis, a small cone on the lower slopes of Mount Erebus; and two types of trachytoid phonolite: one found in the region of Hut Point Peninsula, and also at Cape Bird; the other, found at Mount Terror, also at Cape Bird, Inaccessible Island, the Dellbridge Islands, and, a related type, at Abbott's Peak on Mount Erebus.

The kenytes, a peculiar type of anorthoclase-phonolite, described originally from Mount Kenya in East Africa, are the dominant recent lavas of Mount Erebus and are almost entirely restricted to the neighbourhood of that volcano.

Several types of basalt are described all carrying olivine, though it is less abundant in some types than in others. Nepheline is not actually identified but microchemical tests indicate that it is a potential mineral of the groundmass of all the basalts examined.

On the question of the relative ages of the different kinds of lava it seems almost certain that at Hut Point and on the mainland opposite Ross Island the fine-grained olivine-basalts are the most recent lavas and the trachytoid phonolites are older. The same applies to the relative ages of basalts and trachytoid phonolites in the Dellbridge Islands, where basalts lie above the trachytic lavas. On the other hand, at Mount Erebus it is the kenytes that form the latest flows, while the porphyritic basalts and the phonolitic trachyte of Mount Cis are older.

At Cape Barne there is some uncertainty as to the relative ages of the kenytes and the Cape Barne basalts (see p. 9). The petrography throws little light on this problem, but more evidence could probably be obtained if chemical analyses were made of the basalts at Cape Barne and of the somewhat similar basalts of the two Razorback islands and Tent Island, and of the trachytoid phonolites of those islands. It seems likely from Debenham's observations that the trachytoid phonolite–basalt lavas of the Razorbacks are derived from an older centre of eruption than the recent craters of Mount Erebus, and that these lavas of the Razorback islands are earlier than most of the Mount Erebus flows. If the Cape Barne basalts are as closely related in time to the basalts of the Little Razorback as they appear to be petrographically it seems likely that those also are earlier than most of the flows on Mount Erebus. This would be in agreement with Debenham's interpretation of the field evidence.

Much more detailed work remains to be done on all these rocks. Indeed the author feels that he has accomplished little more than a rather superficial description and a rough classification of the volcanic rocks collected by the Expedition. The treatment of the basalts is particularly unsatisfactory but, without more chemical analyses, not much more can be done with these rocks in which one can only guess at the composition of the groundmass even when that is not wholly glassy. The microchemical tests employed have served only to indicate the presence, or potential presence, of feldspathoids. The tests gave positive reactions for feldspathoids in nearly every case.

When one seeks to find whether the volcanic rocks are members of one or more differentiation series one finds that the chemical analyses available are too few to warrant very definite deductions from differentiation diagrams and other recognized methods of plotting analyses. A particularly serious weakness in the series is the lack of any analyses of the basalts of Mount Erebus with the abundant tabular insets of plagioclase (pp. 68–70). However, in spite of these disadvantages, some diagrams have been prepared and certain observations may be made.

'Niggli values' plotted against *si* provide a differentiation diagram (Fig. 5) that can be compared with similar diagrams plotted for instance by C. Burri and P. Niggli for certain Atlantic, Pacific, and Mediterranean series of rocks. Even the few analyses available of South Victoria Land volcanic rocks show rather wide scatter and little tendency to fall closely on a smooth curve, but the olivine-basalts of the Hut Point Peninsula and of the Ferrar Glacier region [Nos. 28, 29, 30 and 31]* make a compact enough group. If one begins by connecting up this group of the olivine-basalts, with *si* around 88, to the other analyses made in the Department of Mineralogy by Prior and others, it will be seen at once that there is a sudden change of trend for all four values,

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* The numbers in brackets here refer to the numbers in the list of analyses plotted in the diagrams (p. 100).

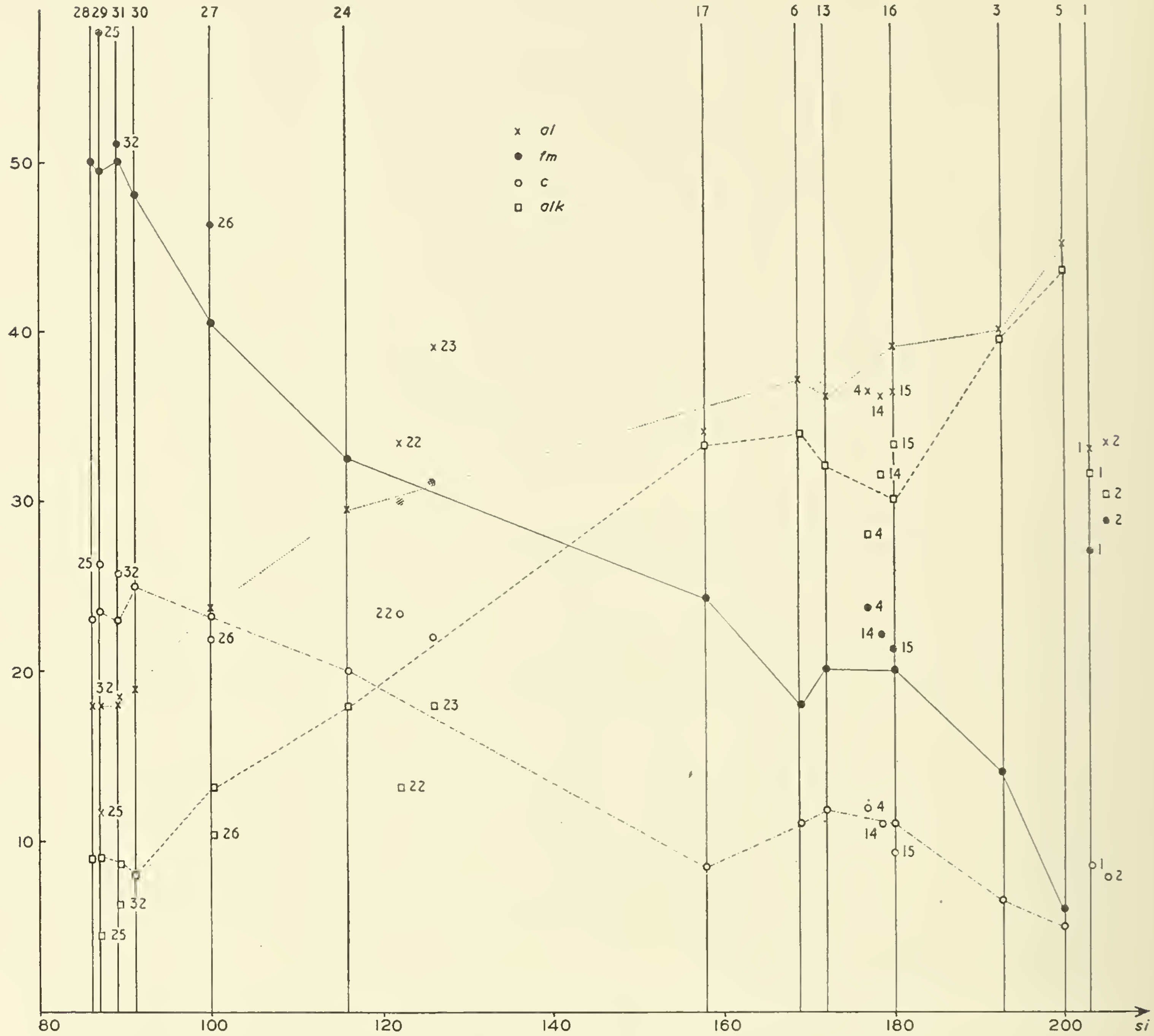

FIG. 5.—Differentiation diagram: 'Niggli values' *al*, *fm*, *c*, *alk* plotted against *si*.

al, *fm*, *c*, and *alk*, between Prior's phonolitic trachyte from Brown Island at *si* = 200, and the Mount Cis 'trachyte' [1] at *si* = 203. Further, it seems that the kenytes [13 and 16] and the kenyte-pumice [17] give values which do not lie on (or even very near) the lines joining values for the Observation Hill type of trachytoid phonolite at *si* = 199 [6] and the Mount Terror type at *si* = 193 [3]. At least this is true for *fm* and *c*, which are high, and for *alk*, which is low; the *al* values are very close to the line for the trachytoid phonolites. In view of these divergences it is tempting to suggest that the lavas of Mount Erebus itself do not fall quite into the same differentiation series as the Hut Point Peninsula–Cape Bird lavas, but it is just here that one needs analyses of the Mount Erebus basalts to see if they also depart from the Hut Point Peninsula types in composition. Until these analyses, at least, are available one cannot tell whether any value should be attached to this suggestion that there are two slightly differing series. In this connection one may note that at the basic end of the diagram, the undescribed limburgite from Mount Erebus [J68](No. 25) (p. 78)] gives figures for *al*, *fm*, and *alk* all far removed from corresponding values for the Hut Point basalts of almost the same *si* value.

As regards the other analyses, the values for the kulaitic basalt from Cape Bird [22] are very low for *alk* and very high for *al*.

The Q–L–M diagram (Fig. 6) shows the same general lining up of the olivine-basalts of Hut Point and Ferrar Glacier, the hornblende-basalt of Mount Terror [24], and the trachytoid phonolites of Observation Hill and Mount Terror types [6 and 3]; and the same departure from this line-up of the Mount Cis 'trachyte' [1 and 2] at one end, and the Mount Erebus limburgite [25] at the other, and much smaller divergence of the leucite-kenyte [16] and the kenyte-pumice [17].

The analyses have also been plotted in the π–k and γ–mg triangular diagrams used by Burri and Niggli (Figs. 7 and 8). π is the ratio of calcium aluminate (*Cal*) of the equivalent norm to the sum of $Ne+Kp+Cal$; and k is the ratio of K_2O to total K_2O+Na_2O in the salic minerals. Similarly, γ is the ratio of calcium orthosilicate of the equivalent norm (*Cs*) to total Ca, Mg, and Fe combined with silica in the 'basis' components *Cs*, *Fo*, *Fa*, and *Fs* (Fe_2SiO_5); and *mg* gives the ratio of MgO to total FeO, MnO, and MgO. In effect the π–k triangle shows how the Na, K, and Ca are distributed in the salic minerals (feldspars and feldspathoids) and the γ–mg triangle shows the distribution of the Fe, Ca, and Mg in the M-components (*Cs*, *Fo*, *Fa*, and *Fs*).

Comparison of these diagrams and of the Q–L–M diagram with the corresponding diagrams published by Burri and Niggli* show a general similarity with the plots for the rocks of the Tristan da Cunha group taken as representative of an assemblage of Atlantic type.

The kenyte divergences may not be wide enough to be important but the Mount Cis 'trachyte' presents such sudden changes in all four quantities, *al*, *alk*, *fm*, and *c*, that they must be significant. The cause for these unusual values is possibly to be found in the great number of inclusions of Beacon Sandstone which the lava has only partly digested (p. 25). At the basalt end of the series, the olivine-basalts of the Cheyenne Crater in the Ferrar Glacier region are also full of inclusions of Beacon Sandstone, but these do not appear to have been so much altered and assimilated as in the Mount Cis

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* Burri (Conrad) and Niggli (Paul), Die jungen Eruptivgesteine des mediterranen Orogens. Erster Haupteil; Zürich, 1945, p. 78 and particularly figs. 24, 27, and 30.

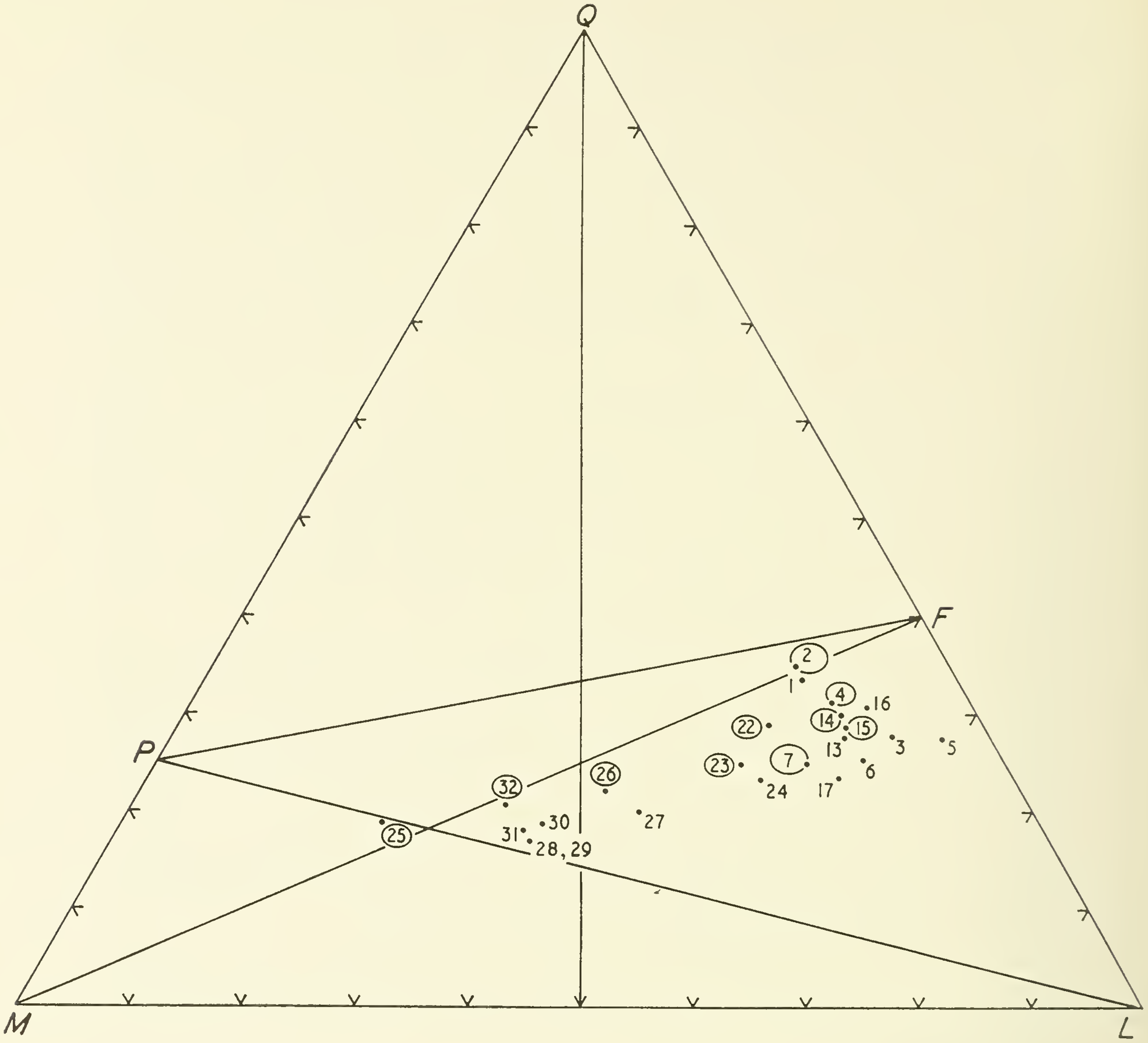

Fig. 6. Q–L–M diagram on which the chemical analyses of the volcanic rocks of the Ross Archipelago are plotted.

'trachyte'. The fact that there is no important difference in composition between the basalts of Hut Point Peninsula and those of the Ferrar Glacier Region would seem to confirm this.*

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* At Sulphur Cones and other centres on the Hut Point Peninsula inclusions are also abundant but these are olivine-nodules and the feldspathic (plagioclase) nodules described in detail by Prior (op. cit. 1907, p. 105–109) and by J. Allan Thomson (op. cit. 1916, pp. 131–4), and they are believed by those authors to be connected genetically with the rocks in which they occur.

The kenytes are to all intents and purposes restricted to the Mount Erebus centre. There is no evidence as to their relation to the porphyritic basalts of Mount Erebus, except that they appear to be the latest ejectamenta of the volcano, whereas the basalts at this centre are evidently older lavas.

At present, no clue to the problem of the kenytes has emerged from the study of this collection. It might be expected that careful study and comparison of the kenytes of

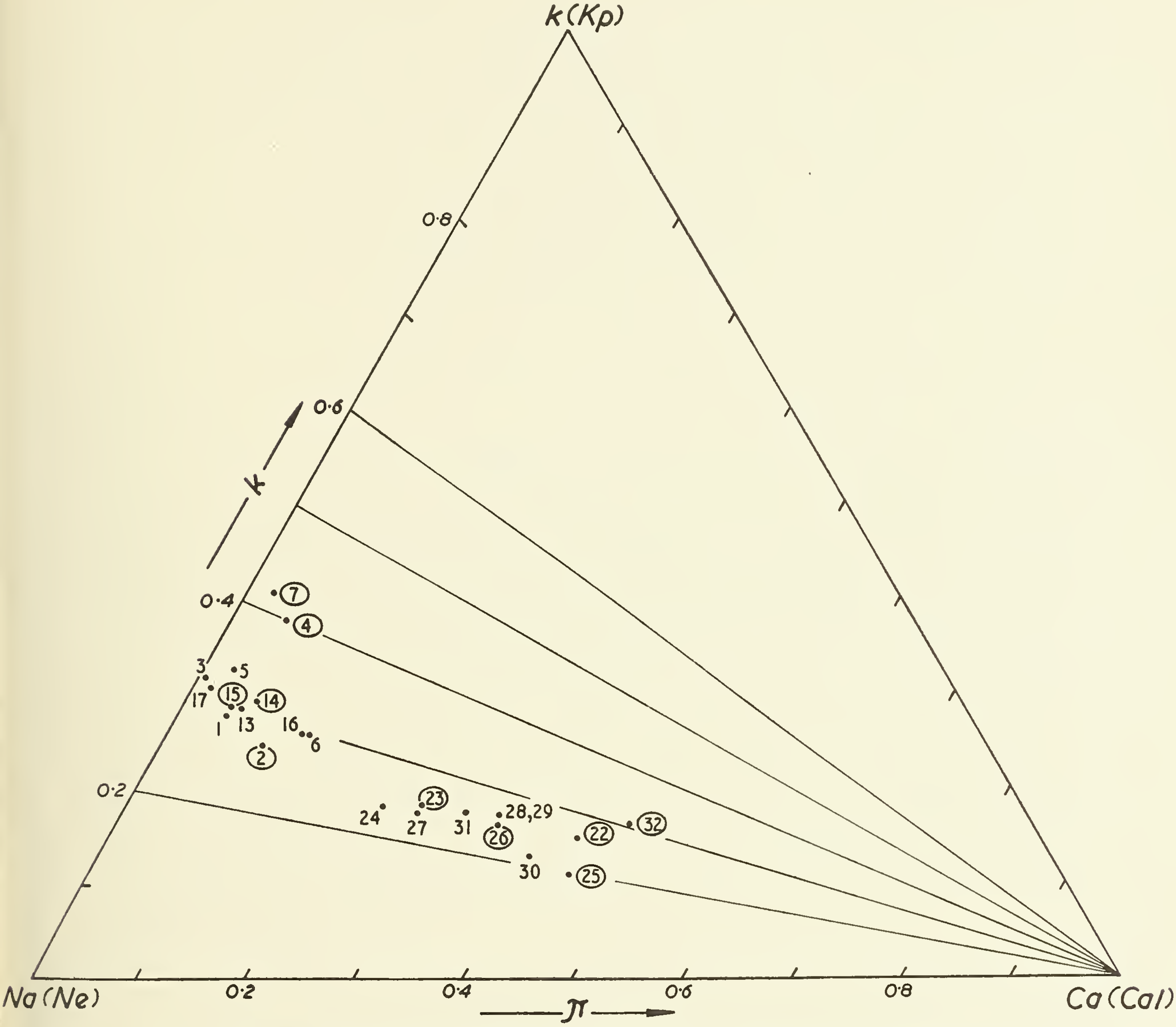

FIG. 7. π–k diagram showing the distribution of Na, K, and Ca in the salic minerals of the equivalent norms.

Mount Erebus, of Mount Kenya, and of Kilimanjaro, and of the conditions under which the kenytes are extruded at these three centres, might reveal some conditions common to all three and so lead to a solution of the problem of the origin of the kenytes. The lavas of Kilimanjaro have recently been studied in the field by members of the Geological Survey of Tanganyika Territory and by members of an expedition from the University of Sheffield and when this work is completed much needed new information about Kiliman-

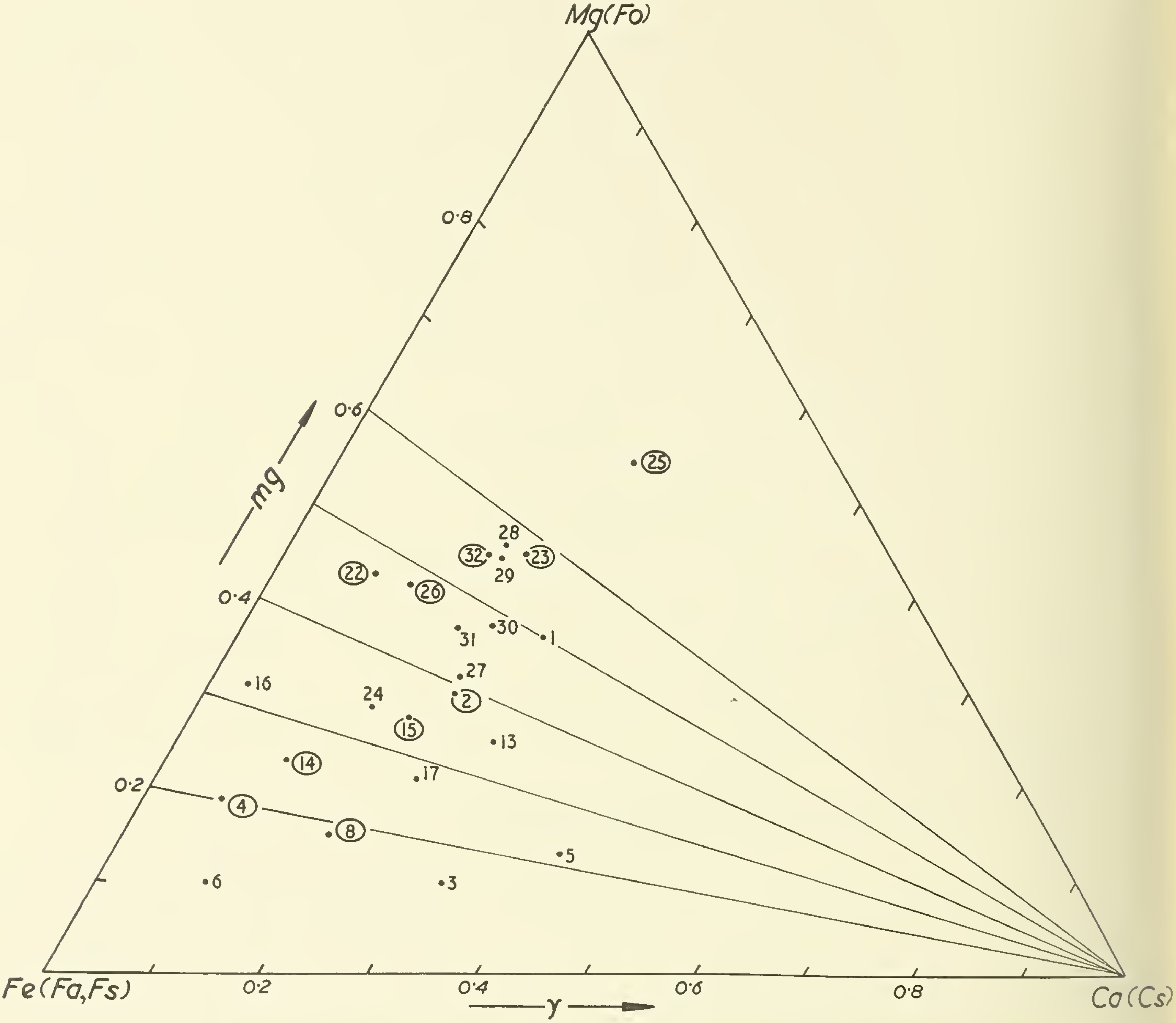

FIG. 8. γ–*mg* diagram showing the distribution of Fe, Ca, and Mg in the femic minerals of the equivalent norms.

jaro will be available. Our knowledge of the higher parts of Mount Kenya is rather limited but it is known that parts of the kenyte lavas have a wholly glassy base, though this is not pumiceous as it is at Mount Erebus. At Kenya too anorthoclase crystals have been thrown out by the volcano in great numbers, so that they form what appear to be beds of some extent. Mixed with the crystals are fragments of compact, black glass.*

The anorthoclase crystals are peculiar in composition and in habit (p. 43). They have frequently been likened to the feldspar insets in the rhomb-porphyries of the Oslo region which have been quite recently studied very thoroughly by C. Oftedahl, who has given a fairly complete picture of the probable history of the formation and extrusion of these rocks.† Some light on the kenyte problem might have been expected from this direction, but it has now been shown that the anorthoclase of the kenytes is not similar in composition to the feldspar of the rhomb-porphyries, and also that neither in composition nor in their mode of extrusion do the rhomb-porphyries resemble the kenytes of Mount Kenya and of Ross Island. There is as yet no clue to the problem of why the insets in the kenytes and in the rhomb-porphyries attained their peculiar 'rhombic shape'.

A few other points of mineralogical interest are perhaps worth mentioning as they may correct some probably erroneous records of rather rare or unusual rock-forming minerals.

The yellow mineral in the trachytoid phonolite of Observation Hill described by Prior (p. 33) is probably not epidote as he thought but a pyroxene owing its yellow colour to some alteration. It may be similar to the pyroxene, near acmite, described by the present author in some of the inclusions in the kenytes (p. 51). The wöhlerite recorded by H. I. Jensen in a 'leucite tephrite' (p. 54) is probably the same mineral. Jensen was probably influenced in identifying the mineral as wöhlerite because of the record of wöhlerite in an erratic (sodalite-syenite) from Cape Royds (see footnote p. 54).

Haüyne is here described from several inclusions in kenytes. This seems to be the first record of this mineral from South Victoria Land.‡

On the other hand the leucites described by Prior in one of the kenytes from Cape Royds and in the glassy hornblende-trachyte of Observation Hill are regarded as doubtful, though several other finds of icositetrahedral crystals in the glassy groundmass of some other kenytes have been made (p. 58). It seems most likely that the rocks described as 'leucite tephrite' and 'leucitophyre' were incorrectly named and should not be recorded as occurring in South Victoria Land. The true nature of the supposed leucites remains unknown.

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* Smith (W. Campbell), Brit. Mus. (Nat. Hist.), Bulletin, Mineralogy, vol. 1, no. 1, 1952.

† Oftedahl (C.), Studies on the igneous rock complex of the Oslo region. XII. The lavas. Skrift. Norske Vidensk. Akad., I. Mat.-Nat. Kl., 1952, No. 3.

‡ Stewart (Duncan, Jr.), On the mineralogy of Antarctica. Amer. Min., 1951, vol. 36, p. 363.

The author offers his thanks to all members of the Department of Mineralogy who have given him their help at various periods, extending over many years, when the work on the volcanic rocks of the Ross Archipelago was in hand; in particular: to Mr. P. M. Game for preliminary work on the basalts of Mount Erebus and Cape Evans; to Mr. Game and Mr. A. H. Weir for determinations of feldspars in basalts; to Mr. D. I. Bothwell, Mr. J. D. Easton, Mr. N. E. Butcher and Mr. K. Chaperlin, for rock analyses made in the Department under Dr. M. H. Hey's supervision; to Mr. D. L. Williams for the photomicrographs; and to Mr. R. T. W. Atkins who redrew all the diagrams on which the analyses are plotted.

Finally the author acknowledges with gratitude the help given in the initial and final stages of the work by Professor Frank Debenham and Sir Raymond E. Priestley, whose patience and forbearance have been almost as great as were their energy and endurance when, in their much younger days, they collected the great numbers of specimens here described.

Additional note

Since the manuscript of this report was sent to the printers Mr. Bothwell has completed analyses of a basalt from Middle Dome, Cape Barne [D24R] and of a similar rock from the summit of Little Razorback Island [D35E]. The results are given in Table VI*a* below with the norms, etc., to correspond with the other tables, I–V. Except for higher SiO_2 and lower CaO in D35E the two analyses are very similar, as was expected. The figures for P_2O_5 are unusually high and TiO_2 also is high. In the C.I.P.W. classification they fall in the same sub-rang as Prior's hornblende-basalt from Mount Terror and Jensen's 'Basic kenyte' from Turk's Head. In the differentiation diagram (Fig. 5) they would occupy a position between these (Nos. 23 and 24) and the basalt from Cape Barne analysed for Jensen (No. 26) and the hornblende-basalt from Hut Point Peninsula (No. 27). By themselves they throw no new light on the differentiation series. The normative plagioclase in both appears very high in *ab*. This may be partly the effect of the high P_2O_5 values, which, requiring much CaO, has the effect of lowering the *di* and *an* and also the *ne* and raising thereby the *ab*. In most of the basalts in the same sub-rang in Washington's Tables the *ab*+*an* makes from 45 to 50 per cent with *ab*:*an* varying around 1:1, and that is about the composition of the plagioclase in the modes of these two analysed rocks and the associated Cape Barne basalts (see p. 88). More detailed work must now be done on the mineral composition of these analysed rocks to make their classification more precise. With the plagioclase basic andesine about An_{47} and An_{48}, and with femic minerals in the norm less than 40 per cent, these rocks might be classified as andesites but for their potential nepheline and their olivine. According to their sub-rang they fall in Lacroix's classification, like the hornblende-basalt of Mount Terror and perhaps some of the Mount Erebus basalts, in his group of 'téphritoïdes' for which there is at present no English equivalent.

TABLE VI.—CHEMICAL ANALYSES, NORMS, ETC. OF LAVAS FROM CAPE BARNE AND LITTLE RAZORBACK ISLAND

24a. Basalt. II .6″.″3.4.
Summit of Little Razorback Island. D. I. Bothwell, anal. D35E.
26a. Basalt. II(III).(5)6.″3.4.
Middle Dome, Cape Barne. D. I. Bothwell, anal. D24R.

TABLE VI*a*
CHEMICAL ANALYSES

	24a	*26a*
SiO_2	46·98	45·26
TiO_2	2·94	3·09
Al_2O_3	16·75	16·93
Fe_2O_3	2·80	2·85
FeO	8·18	8·79
MnO	0·29	0·29
MgO	3·99	3·98
CaO	8·41	9·32
Na_2O	4·81	4·58
K_2O	1·97	2·04
H_2O+	1·28	0·77
H_2O-	0·31	0·20
P_2O_5	1·48	1·66
ZrO_2	tr.	tr.
SrO	tr.	tr.
BaO	0·04	0·05
	100·23	99·81

TABLE VI*b*
C.I.P.W. NORMS

	24a	*26a*
or	11·68	11·9
ab	29·34	23·06
an	18·90	19·8
ne	5·96	8·52
di	10·52	13·05
ol	9·63	9·17
mt	4·18	4·18
il	5·62	5·93
ap	3·7	3·90

TABLE VI*e*
'NIGGLI VALUES'

	24a	*26a*
si	118	110
al	24	24
fm	38	38
c	22·5	24
alk	14·5	14
ti	0·55	0·56
k	0·21	0·22
mg	0·39	0·385
c/fm	0·59	0·63
qz	−68·5	−76
p	1·65	1·7
π	0·26	0·27
γ	0·17	0·186

TABLE VI*c*
CATION PER CENT

	24a	*26a*
SiO_2	44·3	42·5
TiO_2	2·1	2·2
$\frac{1}{2}Al_2O_3$	18·8	18·8
$\frac{1}{2}Fe_2O_3$	2·04	2·0
FeO	6·42	6·9
MnO	0·22	0·2
MgO	5·63	5·6
CaO	8·46	9·4
$\frac{1}{2}Na_2O$	8·7	8·3
$\frac{1}{2}K_2O$	2·37	2·4
$\frac{1}{2}P_2O_5$	1·24	1·3
	100·24	99·6

TABLE VI*d*
EQUIVALENT NORMS

	24a	*26a*
Or	12·0	12
Ab	31·0	23·25
An	19·25	20·25
Ne	7·5	10·95
Wo	5·0	6·4
En	3·0	3·8
Fs	2·0	2·6
Fo	6·1	5·6
Fa	3·9	3·9
Il	4·2	4·4
Mt	3·0	3·0
Ap	3·4	3·5
	100·35	99·65

TABLE VI*f*.
'BASIS'

	24a	*26a*
Cp	3·1	3·3
Ru	2·1	2·2
Kp	7·1	7·1
Ne	26·0	25·0
Cal	11·6	12·0
Cs	4·1	5·0
Fo	8·5	8·5
Fa	10·0	10·5
Fs	3·05	3·0
Q	24·7	24·0
Q	26	25·25
L	47	46·5
M	27	28·25

LIST OF ANALYSES PLOTTED IN THE DIAGRAMS

1. Phonolitic trachyte, Mount Cis, Mount Erebus. D. I. Bothwell, anal. B.M. 1911, 135, 13.
2. Phonolitic trachyte, Mount Cis, Mount Erebus. Hogarth, anal. J13.
3. Trachytoid phonolite, Cape Crozier, Mount Terror. G. T. Prior, anal. B.M. 87171, 188.
4. 'Phonolitic trachyte' (Prior), Scott Island. G. T. Prior, anal. B.M. 87171, 973.
5. 'Phonolitic trachyte' (Prior), Brown Island. G. T. Prior, anal. B.M. 87171, 607.
6. Trachytoid phonolite, Observation Hill. G. T. Prior, anal. B.M. 87171, 277.
7. Trachytoid phonolite, Cape Bird. Burrows and Walkom, anal. J18.
13. Kenyte, Deviation Hill, Cape Evans. D. I. Bothwell, anal. D70E.
14. Vitrophyric Kenyte, Cape Evans. Hogarth, anal. J25.
15. Kenyte, Cape Evans, Ross I. Hogarth, anal. J5.
16. 'Leucite-kenyte' (Prior), Cape Royds. G. T. Prior, anal. 818.
17. Kenyte-pumice, Mount Erebus. J. D. Easton, anal. B.M. 1953, 86 (6).
18. Pumice, Mount Erebus. Burrows and Walkom, anal.
19. Kenyte, central core of Mount Kenya. G. T. Prior, anal. G499.
20. Kenyte, lava-flow from summit of Mount Höhnel, Mount Kenya. G. T. Prior, anal. G462.
21. Phonolite-obsidian (Kenyte-glass). Campi Sheitani (13,000 feet), Mount Kenya. M. H. Hey, anal. B.M. 1948, 195.
22. 'Kulaitic Basalt' (Jensen), Cape Bird. Burrows and Walkom, anal. P325(648).
23. 'Basic kenyte, Plagioclase Kenyte', Turk's Head. Hogarth, anal. J11(1920).
24. Hornblende-basalt, foot of Mount Terror. G. T. Prior, anal. B.M. 85752(93).
25. 'Limburgite', Mount Erebus. Burrows and Walkom, anal. J68.
26. Basalt poor in olivine, Cape Barne. Hogarth, anal. J4(1914).
27. Hornblende-basalt, Sulphur Cones, Hut Point Peninsula. G. T. Prior, anal. B.M. 87171(385).
28. Olivine-basalt, The Gap, Hut Point Peninsula. G. T. Prior, anal. B.M. 87171(826).
29. Olivine-basalt, Ridge Road, Winter Quarters, Hut Point Peninsula. G. T. Prior, anal. B.M. 87171, (326).
30. Olivine-basalt, Cheyenne Crater, Ferrar Glacier region. N. E. Butcher and D. I. Bothwell, anal. D8F.
31. Olivine-basalt, lava-flow, 'Black Hill', Taylor Valley, Ferrar Glacier region, D. I. Bothwell, anal. D2F.
32. 'Leucite Tephrite', Top of Crater Hill, Hut Point Peninsula. Hogarth, anal. J31.

INDEX OF SPECIMENS MENTIONED BY NUMBER IN THE REPORT ON THE VOLCANIC ROCKS OF ROSS ISLAND, ETC.

MOUNT EREBUS REGION

			Page
D1O	Olivine-basalt with insets of plagioclase in star-shaped groups	Moraine at top of Crater Glacier, Mount Erebus.	5, 68, 69
D2O	„ „	Moraine at top of Crater Glacier, Mount Erebus.	5, 68, 69
D3O	„ „	Moraine at top of Crater Glacier, Mount Erebus.	68, 69
D4O	Olivine-basalt with tabular insets of plagioclase in star-shaped groups	Moraine at top of Crater Glacier.	69
D5O	"Kenyte"	Ridge above Station E, [Point 7650].	4

			Page
D70	Kenyte	Ridge above Station E [Point 7650].	4, 50
D80	Kenyte	Station F.	
D90	Trachytoid phonolite (Mount Terror type)	Associated with the trachyte [D190] on Abbott's Peak (Demetri Peak).	6, 29
D100	Kenyte, and basalt with insets of plagioclase	Moraine at top of Crater Glacier.	57, 58, 69
D110	Kenyte	Station E [Point 7650].	5
D120	Kenyte	Ridge above Station E.	5
D130	Kenyte	Station E.	5
D140	Basalt poor in olivine	Station C.	
D150	Kenyte	Ridge running down to The Fang.	
D160	Kenyte, and basalt with insets of plagioclase	Moraine at top of Crater Glacier.	5, 56, 57, 69, 70
D170	Kenyte	Station F.	
D180	Porphyritic basalt with brown hornblende	Base of Abbott's Peak.	6, 80
D190	Trachytoid phonolite	Bedded near summit of Abbott's Peak.	6, 29, Pl. 3, Fig. 5
D200	Basalt with insets of plagioclase in star-shaped groups; also basalt with insets of plagioclase, augite, and olivine	Boulders, Lower Fang.	5, 12, 70, 71, 73
D220	Kenyte	Hooper's Shoulder.	4, 57, Pl. 4, Fig. 5
D240	Basalt with insets of plagioclase in star-shaped groups	Moraine below Old Fang.	5, 69
D250	Tuff	Cone G.	6
D260	Kenyte	Base of cliff on west side of Deep Lake, Cape Barne.	7, 57, Pl. 4, Fig. 4
D270	Tuff	Cone H.	6
D280	Basalt poor in olivine	Pyramid, west side scree, Cape Barne.	9, 88, Pl. 6, Fig. 4
D290	Porphyritic basalt with brown hornblende	Loose, red weathered on summit of Abbott's Peak.	6, 80

Cape Royds region

D1R	Kenyte	Flow, 50 yards W. of High Peak.	7
D2R	Basalt	Erratic near Point E.	
D3R	Kenyte	Valley above Blacksand Beach.	7, 57, 58, Pl. 5, Figs. 3 and 4
D6R	Kenyte	Point A.	7, 49, 56, Pl. 4, Fig. 2
D7R	Tuff with glassy basalt lapilli	Erratic, above Backdoor Bay.	12
D9R	Kenyte	Point beyond Horseshoe Bay.	7, 56
D10R	Kenyte	Point beyond Horseshoe Bay.	7, 56
D11R	Basalt	Erratic, above Backdoor Bay.	
D12R	Kenyte	Point D.	7
D13R	Kenyte	Point B.	7
D14R	Kenyte	Base of cliff above Blacksand Beach.	7
D15R	Kenyte	Point A.	7, 49, 56
D16R	Kenyte	Point E.	7, 56
D18R	Phonolitic trachyte, etc.	Miscellaneous erratics (volcanic).	7
D19R	Phonolitic trachyte	Mount Cis.	26
D20R	Tuff	Tuff cone H.	6
D21R	Kenyte	Cliff face in Deep Lake valley; the lower of the two kenyte flows.	7

			Page
D23R	Tuff	Cone G.	6
D24R	Basalt	Middle Dome, Cape Barne.	9, 86, 88, 98, anal p. 99, Pl. 6, Fig. 3
D26R	Kenyte	Erratic near Cape Barne.	50

CAPE EVANS REGION
(including Tent Island, and the Razorback Islands)

D1E	Kenyte	Lava-flow in situ at NE. end of beach, Cape Evans.	56
D5E	Kenyte	Erratics, close to the hut, Cape Evans.	11
D8E	Kenyte	In situ from lava-flow under the Barne Glacier.	11, 49, 55
D11E	Kenyte	Upper slope of Barne Glacier moraine.	5, 11, 58
D12E	Inclusions (?) in Kenyte	From The Ramp.	5, 50–54, 72, Pl. 5, Fig. 6
D17E	Inclusion in 'kenyte'	Northern half of Tent Island.	14, 54
D18E	Basalt	South summit of Tent Island.	14
D19E	'Basalt' in typical kenyte	Inclusion in lava close to 17, northern half of Tent Island.	14
D21E	Trachyte	Outcrop at base of Tent Island, on west side, beside small delta.	13, 29
D24E	Trachytoid phonolite (Mount Terror type)	Fragments from tuff on west side of Tent Island.	14, 28
D26E	Kenyte	Base of outcrop at The Slipper, E. of C. Evans.	5, 11, 50, 54, 55
D27E	Kenyte	Upper edge of outcrop of lava at The Slipper.	11, 57
D28E	Trachytoid phonolite (Mount Terror type)	East end of Big Razorback Island.	29
D29E	Trachytoid phonolite (Mount Terror type)	West base of Big Razorback I., below The Turret.	14, 29
D30E	Trachytoid phonolite (Mount Terror type)	North-east end of Big Razorback I., near summit.	14, 29
D31E	Trachytoid phonolite (Mount Terror type)	From base of Big Razorback I., 'in the middle'.	14, 29
D32E	Trachytoid phonolite (Mount Terror type)	Base of cliff at east end of Little Razorback.	14
D33E	Basalt	Lava, base at west end of Little Razorback.	14, 88
D34E	Basalt	Base, south-west end of Little Razorback Island.	14, 88
D35E	Basalt poor in olivine	Summit of Little Razorback Island.	14, 88, 98, anal. p. 99
D37E	Tuff	40 feet above sea-level up valley on W. side of Tent Island.	14
D38E	Tuff with lapilli of basalt	Outcropping at SW. end of Tent Island.	14, 72
D39E	Basalt with insets of plagioclase, olivine, and augite	Summit of Tent Island above the gully on west side.	14, 71
D42E	Basalt	Base of cliffs on S. side of Tent Island.	14, 69, 71
D43E	Basalt	Boulders from tuff at NW. end of Tent Island.	13, 14, 88
D44E	Basalt	Lava above tuff on west side of Tent Island.	13
D45E	Basalt	Lava below tuff on west side of Tent Island.	13
D46E	Basalt with insets of plagioclase, olivine, and augite	Intruding through tuff on SW. side of Tent Island.	14, 71, 72
D47E	Basalt	Lava bedded above tuff, SE. end of Tent Island.	14, 69
D51E	Phonolitic trachyte	Erratic collected by C. S. Wright, Tent Island.	14

			Page
D52E	Trachytoid phonolite (Mount Terror type), and Kenyte inclusion	Inclusions from near summit of Tent Island. Collected by C. S. Wright.	28, Pl. 2, Fig. 1
D54E	Kenyte, wind-worn erratic	Erratic on The Ramp.	Pl. 1, Fig. 1
D56E	Kenyte, etc.	Collected by C. S. Wright, Tent Island.	
D59E	Kenyte with grey inclusion	Collected by Demetri at Land's End, Cape Evans.	53
D61E	Kenyte and 'basic kenyte', and basalt	Collected by Demetri on Tent Island.	14, 56, 58, 71, 75, Pl. 4, Fig. 6
D62E	Haüyne-bearing inclusion	In 'Antarcticosaurus', a weathered block of kenyte east of Skua Lake, Cape Evans.	53
D68E	Kenyte	Erratic from Deviation Hill, Cape Evans.	5, 49–51, Pl. 4, Fig. 3
D69E	Kenyte	Erratic from High Cliff, Cape Evans.	59
D70E	Kenyte	Erratic from Deviation Hill, E. end of The Trench, Cape Evans.	50–52, 55, 59, 61, 63, 64, anal. p. 64, Pl. 4, Fig. 1

TURK'S HEAD

D1T	Basalt, glassy	Collected by T. Gran, Turk's Head.	12
D2T	Kenyte with plagioclase xenocrysts (?)	Summit of Turk's Head.	12, 75
D4T	Kenyte with plagioclase xenocrysts (?)	Lava from east summit cone; Turk's Head.	12, 75
D5T	Kenyte, glassy	Summit of Turk's Head, in debris, collected by T. Gran.	12, 58
D7T	Tuff	Summit of Turk's Head.	12
D8T	Basalt with insets of plagioclase, olivine, and augite	Base of Turk's Head.	12, 72, 73
D9T	Basalt with tabular insets of plagioclase	Small block in tuff at summit of Turk's Head.	12, 72
D10T	Tuff	From the base of Tuff Bluff.	11

INACCESSIBLE ISLAND

D1I	Trachytoid phonolite (Mount Terror type)	Lowest shore cliffs on eastern end of island.	28
D2I	Trachytoid phonolite (Mount Terror type), glassy variety	50 feet up, on eastern cliffs.	28
D3I	Trachytoid phonolite	Lower northern slopes.	13
D5I	Olivine-basalt with plagioclase insets	Northern lower cliffs.	13, 69
D6I	Basalt, glassy	50 feet up, on eastern cliffs.	13
D7I	Trachytoid phonolite (Mount Terror type), with yellow pyroxene	From scree at base of eastern cliffs.	28, 29, 33
D10I	Basalt with insets of plagioclase	Typical [lava] from upper part of the island.	13, 73
D14I	Haüyne-bearing basic kenyte	Apparently in situ (upper part of island).	54
D17I	Trachytoid phonolite (Mount Terror type)	From weathered face at east end.	28
D20I	Basalt with insets of plagioclase	At the summit at the west end, in situ.	13, 73
D24I	Trachytoid phonolite (Mount Terror type)	East Cape.	28, Pl. 3, Fig. 6
D25I	'Basic kenyte'	Weathered block from summit of the island.	12, 14, 74
D26I	Basalt with insets of plagioclase	At base [of cliff] near couloir.	13, 73
D27I	Basalt with insets of plagioclase, olivine, and augite; boulder found with 'Trachyte'	From upper slopes.	13, 72
D30I	Basalt with insets of plagioclase, augite, and olivine	At top of East Peak, in situ.	13, 72

Hut Point Peninsula

			Page
D1H	Olivine-basalt	From Harbour Heights.	76, 88, 89
D2H	Trachytoid phonolite	From Observation Hill.	31, 32
D3H	Trachytoid phonolite	From crest of Crater Heights.	32–4, Pl. 3, Fig. 3
D5H	Hornblende-bearing basalt	Large boulder at top of Ski Slope.	80
D10H	Augite crystals and matrix	NW. side (base) of Observation Hill.	16
D11H	Augite crystals	From the lavas at top of Ski Slope.	16
D18H	Olivine-basalt	Flow, 100 yards to NE. of Castle Rock.	78
D20H	Olivine-basalt	From Harbour Heights.	77, Pl. 6, Fig. 1
D21H	Tuff	From Hutton Cliffs, collected by T. Gran.	16
D23H	Palagonitic basalt tuff	From Boulder Cones.	15, 77
D24H	'Sanidinite' and inclusions	On Sulphur Cones.	16
D25H	Olivine-basalt	Point B, between Fortress Rocks and Crater Hill.	77, Pl. 6, Fig. 2
D28H	Palagonitic basalt-tuff	From Boulder Cones.	15
D33H	Olivine-basalt	Fortress Rocks.	77
249*	Hornblende-bearing basalt	Half-moon Crater.	16, 80, 81
267*	Hornblende-bearing basalt	Hut Point.	80
226*	Olivine-basalt	Western Corner, Crater Heights.	76, 89
260*	Olivine-basalt	Mound 100 ft. high immediately below Harbour Heights, about 1 mile from the hut, in situ.	76, 89
217*	Trachytoid phonolite, 'Lapilli trachyte'	Ridge running up west side of Observation Hill.	30
218*	Trachytoid phonolite	True summit, Observation Hill.	32, 33
219*	Trachytoid phonolite	S. summit, Observation Hill.	32
220*	Trachytoid phonolite	Point D, Crater Heights.	32, 33
261*	Olivine-basalt	Harbour Height rocks, highest point before first crater.	79
227*	Hornblende-bearing basalt	in situ, S.W. lip of Middle Crater, Point C.	80

* These are serial numbers under B.M. 1953, 86, in the register of rock collections in the Department of Mineralogy.

Ferrar Glacier and Koettlitz Glacier regions

D2F	Basalt	From the basalt-capped hill at base of Dry Valley glacier.	anal. p. 84, 86, 89, 90, Pl. 6, Fig. 6
D8F	Basalt; scoria	From Cheyenne Crater.	19, anal. p. 84, 89, 90, Pl. 6, Fig. 5
D16F	Basalt	From Cheyenne Crater.	19, 89, 90
D3K	Basalt	Collected by T. G. Taylor from lava-flow beside Howchin Glacier.	19, 88
D5K	Basalt and inclusions	From lava-flow beside Howchin Glacier (same locality as 3).	19, 88
D9K	Basalt	From moraine opposite Heald Island.	
D13K	Basalt	'Cape Olivine'.	19

SPECIMENS COLLECTED ON THE BRITISH ANTARCTIC EXPEDITION, 1907–9, RE-DESCRIBED OR REFERRED TO BY NUMBER IN THIS REPORT

Number	Name in the 1907–9 report and locality	Reference	Reference in this report	Page
J1	Phonolitic trachyte, Mount Cis.	p. 99, pl. I, figs. 1 and 2.	Phonolitic trachyte (Mount Cis type)	24
J2	Basalt poor in olivine, C. Barne.	p. 112, pl. V, fig. 3.	Olivine-basalt	87
J3	Kaersuetite (?) Aegirine-augite Trachyte, Observation Hill.	p. 101, pl. 1, figs. 3 and 4	Trachytoid phonolite (Observation Hill type)	32
J4	Basalt poor in olivine, C. Barne.	pp. 112 and 114	Olivine-basalt	anal. p. 84, 87, 88
J5	[Acid] Kenyte, C. Evans.	p. 106, anal. p. 110	Kenyte	anal. p. 64, 50, 55, 63
J6	Augite Andesite, C. Barne.	p. 112	Olivine-basalt	87
J9	Limburgite, Observation Hill.	p. 116	Olivine-basalt	78
J11	Plagioclase Kenyte, Turk's Head.	p. 108, pl. III, fig. 2	Olivine-basalt	anal. p. 82, 12, 73
J12	Trachydolerite breccia, parasitic cone on, Mount Erebus.	p. 109, pl. III. fig. 4	Tuff	6
J13	Phonolitic trachyte, Mount Cis.	p. 99, anal., p. 98	Phonolitic trachyte (Mount Cis type)	anal. p. 37, 23, 25, Pl. 3, Fig. 1
J15 J16	Trachyte, transitional between trachyphonolite and augite andesite, Inaccessible Island.	p. 103	Trachytoid phonolite (Mount Terror type)	28
J18	Altered Phyro-hornblende Trachyte, Cape Bird.	p. 119, pl. III, fig. 5, anal. p. 120	Hornblende-bearing 'trachyte'	anal. p. 37, 33
J20	Basalt poor in olivine, C. Barne.	p. 113	Olivine-basalt	87, 88
J21	Phonolitic Trachyte, Inaccessible Island	p. 102	Trachytoid phonolite (Mount Terror type)	28
J22	Magnetite Basalt, C. Barne.	p. 117, pl. IV, fig. 5	Olivine-basalt	87
J24	Basalt without olivine, C. Barne.	p. 113	Basalt	87
J25	Vitrophyric Kenyte (The Skuary), C. Evans.	p. 106, pl. II, fig. 3, anal. p. 110	Kenyte	anal. p. 64, 50, 57, 63, Pl. 5, Fig. 5
J31	Leucite Tephrite, top of Crater Hill.	p. 111, pl. IV. fig. 3	Olivine-basalt	anal. p. 84, 71
J32	Phonolitic trachyte, Mount Cis.	p. 100	Phonolitic trachyte (Mount Cis type)	24
J36	Kulaite, Cape Bird.	p. 121, pl. III, fig. 6	Hornblende-bearing basalt	81
J40	[Acid] Kenyte (The Skuary), C. Evans.	p. 106, pl. II, fig. 1	Kenyte	50, 54
J41	Trachydolerite, Inaccessible Island.	p. 110	(?) Tephritic basalt	72
J46	[Basic] Kenyte Agglomerate, Turk's Head.	p. 108	Olivine-basalt	73
J47	[Acid] Kenyte (The Skuary), C. Evans.	p. 105	Kenyte	50, 54, 55
J49	Olivine Basalt, C. Barne.	p. 114, pl. V, fig. 2	Olivine-basalt with tabular insets of plagioclase	69
J55	Basic Kenyte, erratic, C. Royds.	p. 108	Olivine-basalt	73
J57	Leucitophyre, erratic, C. Royds.	p. 111, pl. IV, fig. 6	Olivine-basalt with tabular insets of plagioclase.	70
J63	[Acid] Kenyte, erratic, C. Royds.	p. 106.	Kenyte	
J68	Limburgite, Mount Erebus.	p. 114, anal. p. 123	Limburgite	anal. p. 84, 78, 92
314	See under 336.			
315	(Not described by H. I. J.), Cape Bird.		Hornblende-bearing trachyte, comparable to Observation Hill type	33
317(630)	Kulaite, Cape Bird.	p. 124	Hornblende-bearing basalt	81
322(642)	Limburgitic Dolerite, Cape Bird.	p. 125	Olivine-basalt	81
325(648)	Kulaite, Cape Bird.	p. 124, anal. p. 120, pl. V, fig. 1.	Hornblende-bearing basalt	ana. p. 82, 81
334(654)	Olivine Basanite, Cape Bird.	p. 125	Olivine-basalt	81
336, 314	(Not described by H. I. J.), Cape Bird.		Trachytoid phonolite (Mount Terror type)	28
341(653)	Trachyphonolite, Cape Bird.	p. 119	Phonolitic trachyte	35

Also: J44, J55, P54, P55, mentioned on p. 50

EXPLANATIONS OF PLATES

PLATE I

FIG. 1. Anorthoclase crystals weathered out on the surface of a wind-worn erratic from The Ramp, Cape Evans. The largest crystals are 3 centimetres long. D54E. ×8/10.

FIG. 2. Blocks of the brown kenyte-pumice of Mount Erebus with large anorthoclase crystals protruding. The big crystal on the right is over 6 centimetres long. B.M. 1953, 86 (2). ×8/10.

PLATE II

FIG. 1. Small block of pale kenyte in normal grey kenyte. From a block near the summit of Tent Island collected by C. S. Wright. The light-coloured block is 11 cm. high. D52E. ×1/2.

FIG. 2. Bombs of grey kenyte in yellow tuff. From Cape Evans; an erratic. Ee. Natural size.

PLATE III

FIG. 1. Phonolitic trachyte. From Mount Cis, Mount Erebus. B.M. 1911, 135(13) = J13. Crossed polaroids. ×25. (p. 24).

FIG. 2. Trachytoid phonolite (Observation Hill type). From west side of Observation Hill, Hut Point Peninsula. B.M. 1953, 86, 217. Crossed polaroids. ×25. (p. 31).

FIG. 3. Trachytoid phonolite (Observation Hill type). From Observation Hill, Hut Point Peninsula. No. 2H. The black crystals are pseudomorphs of basaltic hornblende. ×25. (p. 32).

FIG. 4. Trachytoid phonolite (Observation Hill type) showing the 'minute colourless circular or roughly six-sided and eight-sided isotropic crystals' described by G. T. Prior in 1907. From Observation Hill. B.M. 87171, 264. ×120. (p. 31).

FIG. 5. Trachytoid phonolite (variant of the Mount Terror type). From the summit of Abbott's Peak, Mount Erebus. D19O. Crossed polaroids. ×25. (p. 30).

FIG. 6. Trachytoid phonolite (Mount Terror type). From East Cape, Inaccessible Island. D24I. Crossed polaroids. ×25. (p. 28).

PLATE IV

FIG. 1. Kenyte. From Deviation Hill, Cape Evans. Showing small insets of olivine and magnetite in a holocrystalline groundmass. D70E. ×50. (pp. 50 and 64, anal.).

FIG. 2. Kenyte, with fine-grained groundmass. Showing micro-insets of olivine and the edge of one of the anorthoclase insets just in the field. From Cape Royds. D6R. ×50. (pp. 49 and 56).

FIG. 3. Kenyte, showing a large inset of pyroxene with included apatite and magnetite in a holocrystalline, rather coarse-grained groundmass. From Deviation Hill, Cape Evans. D68E. ×50. (p. 49).

FIG. 4. Kenyte, showing type of groundmass described as hyalopilitic. From the west side of Deep Lake, Cape Barne. D26O. ×50. (p. 57).

FIG. 5. Kenyte, showing anorthoclase insets with many inclusions of dark glass, in a dark glassy base. From Hooper's Shoulder, Mount Erebus. D22O. ×8. (p. 57).

FIG. 6. 'Basic kenyte' in which some of the feldspar insets are plagioclase, showing a broken inset of plagioclase and a micro-inset of olivine in a kenyte-type of groundmass. From Tent Island. D61E(d). ×40. (p. 75).

PLATE V

FIG. 1. Kenyte, showing in a glassy groundmass, small feldspars and one of the 'rounded, isotropic crystals of leucite' described by Prior (1907, p. 111). From Cape Royds. B.M. 87171, 818. ×50. (p. 56).

FIG. 2. One of the 'small, rounded isotropic crystals of leucite' with 'characteristic central and marginal inclusions of magnetite and augite of the base' (Prior, 1907, p. 111). Part of the same field as Fig. 1. B.M. 87171, 818. ×270. (p. 56).

Fig. 3. Kenyte with transparent, fawn-coloured, glassy base with stout microliths of feldspar, and smaller augites, and magnetites. From a valley above Blacksand Beach, Cape Royds. D3R. ×80. (p. 57).

Fig. 4. Crystal of icositetrahedral habit in the glass of the specimen figured in Fig. 3. ×450. (p. 57).

Fig. 5. Kenyte with glassy base, showing abundant crystallites and slender feldspar microliths. A specimen described by H. I. Jensen. From Cape Evans. J25 = B.M. 1911, 135, 25. ×50. (p. 57).

Fig. 6. Kenyte, an unusual variation with a devitrified glassy base. Perhaps an inclusion in a later lava or a 'bomb'. An erratic from The Ramp, Cape Evans. D12E (c). ×40. (p. 53).

PLATE VI

Fig. 1. Olivine-basalt. A type relatively feldspar-rich, showing long laths of plagioclase with small prisms of augite, grains of magnetite, and interstitial colourless base (nepheline). A group of micro-insets of olivine is shown near the lower edge of the field. From Harbour Heights, Hut Point Peninsula. D20H. ×50. (p. 77).

Fig. 2. Olivine-basalt. The limburgite-like type, showing inset of olivine, small augites, and plagioclase laths in a dense glassy base. From point B, between Fortress Rocks and Crater Hill, Hut Point Peninsula. D25H. ×50. (p. 77).

Fig. 3. Basalt poor in olivine, with small insets of plagioclase and abundant plagioclase laths in the groundmass. From Middle Dome, Cape Barne. D24R. ×40. (p. 87).

Fig. 4. Basalt poor in olivine with abundant micro-insets and laths of plagioclase in a fine-grained, dense groundmass. From The Pyramid, Cape Barne. D28O. ×40. (p. 88).

Fig. 5. Olivine-basalt, showing micro-insets of augite and of olivine and many small laths of plagioclase in a very fine-grained groundmass. From Cheyenne Crater. Ferrar Glacier region, South Victoria Land. D8F. ×50. (p. 89).

Fig. 6. Olivine-basalt, vesicular, showing a micro-inset of plagioclase and many of olivine (white) in a fine-grained groundmass with many microliths of plagioclase. From the lava-flow on 'Black Hill', Ferrar Glacier region, South Victoria Land. D2F. ×50. (p. 89).

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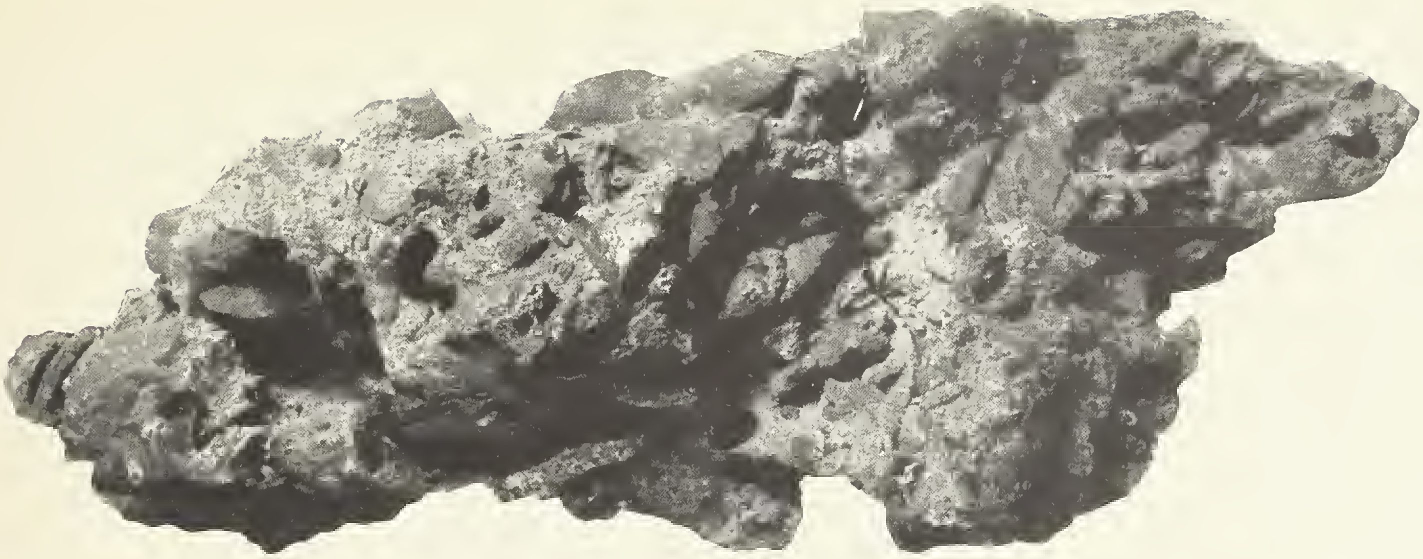


Fig. 1

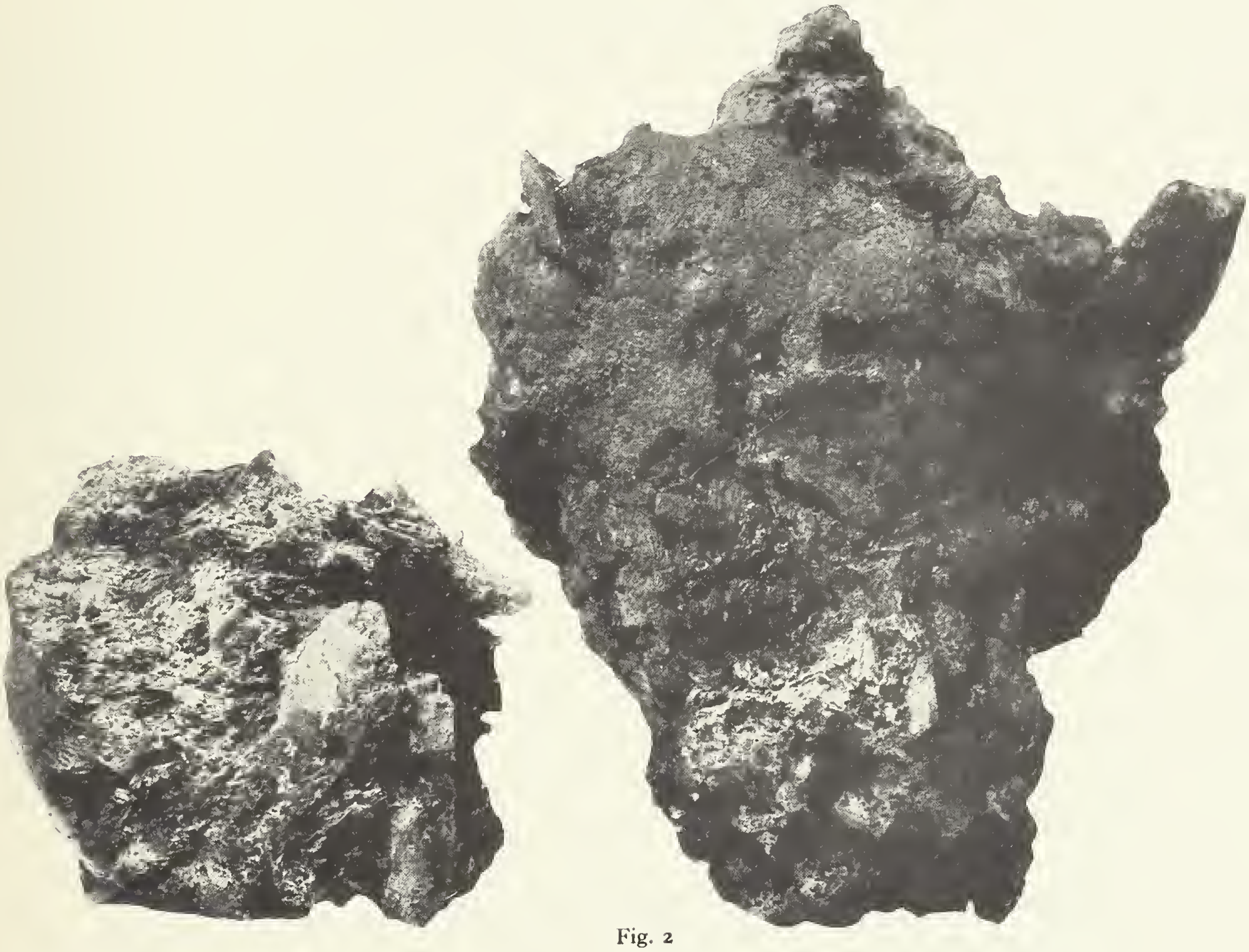
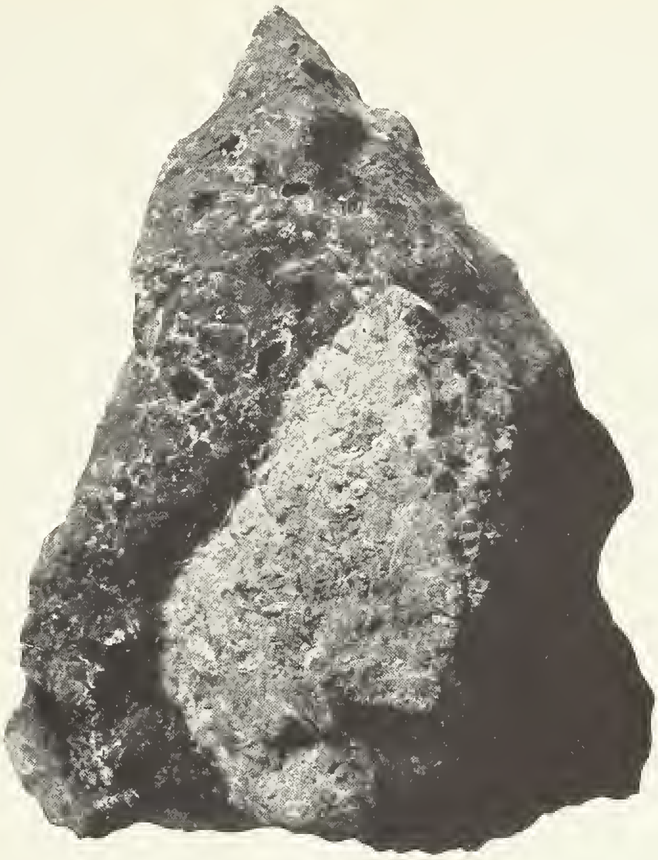


Fig. 2

Brit. Mus. (Nat. Hist.), photo.

KENYTE AND PUMICE, MOUNT EREBUS, ROSS ISLAND



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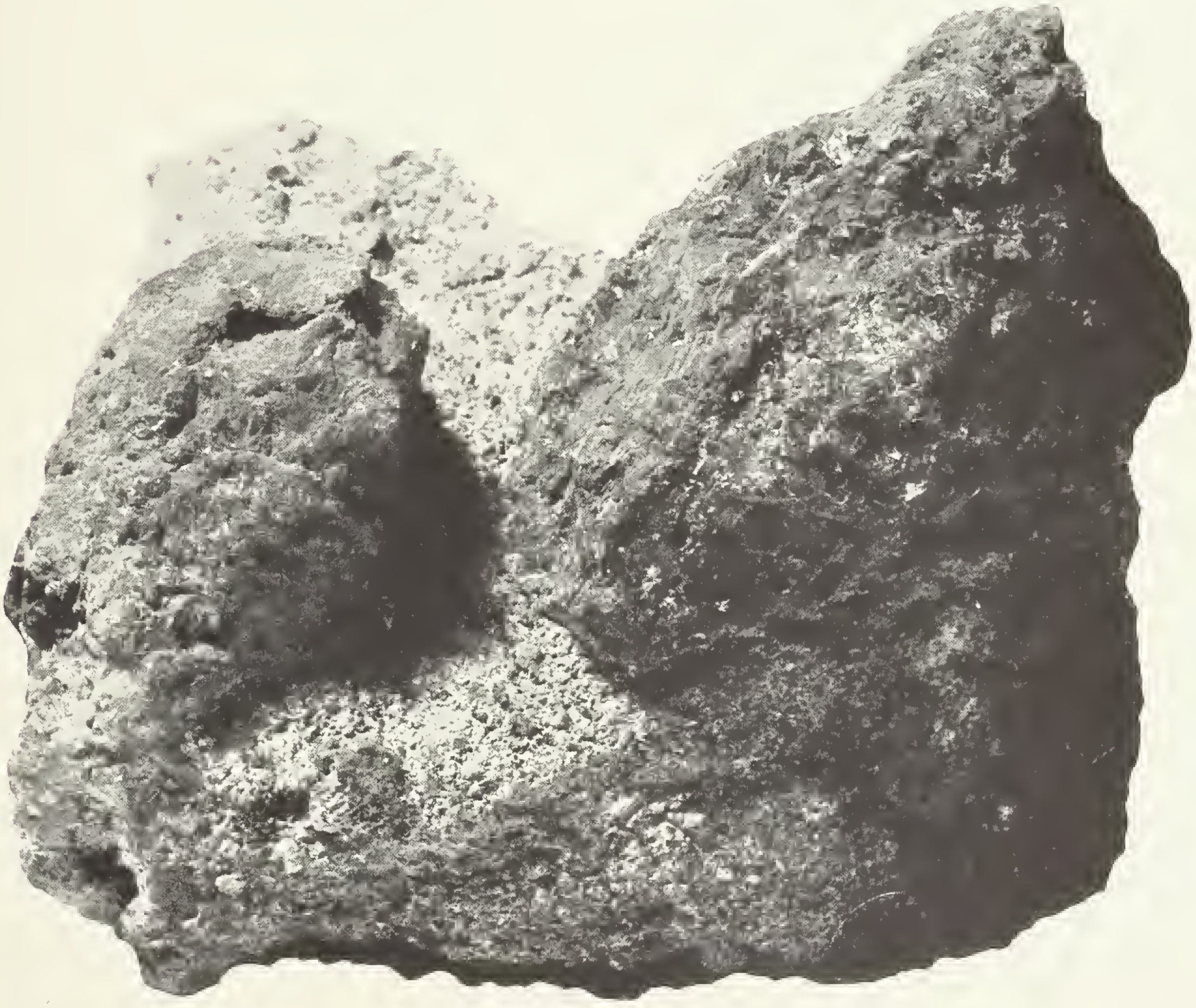
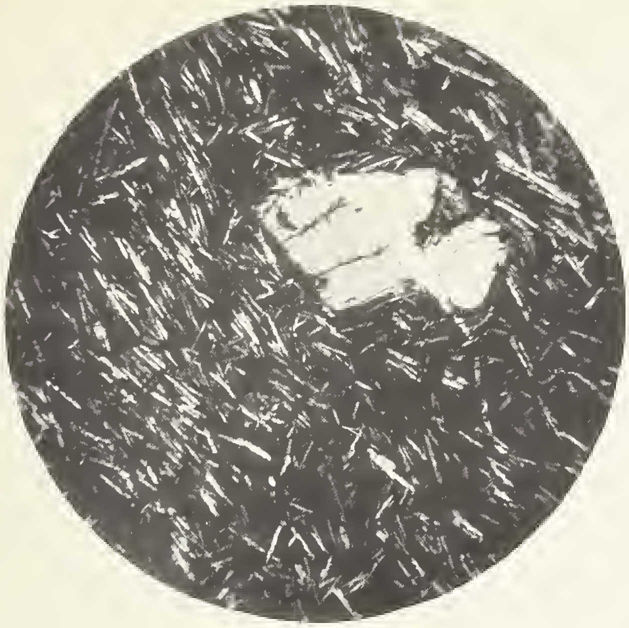


Fig. 2

Brit. Mus. (Nat. Hist.), photo.

KENYTE 'BOMBS' FROM TENT ISLAND AND CAPE EVANS, ROSS ISLAND.



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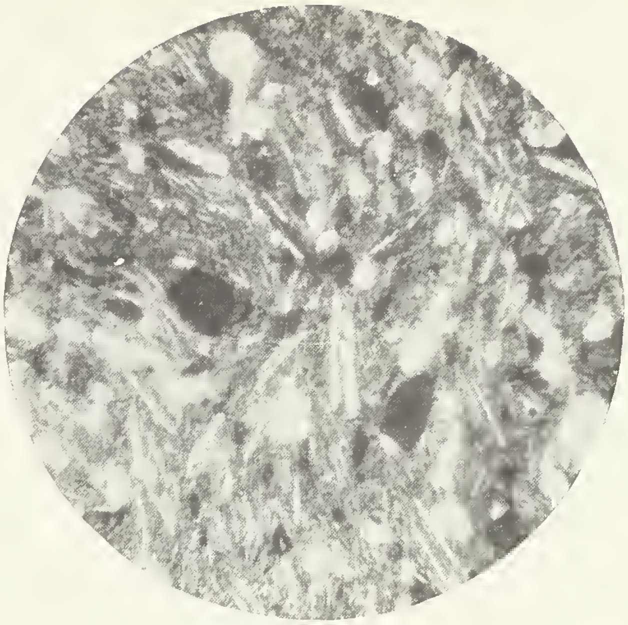

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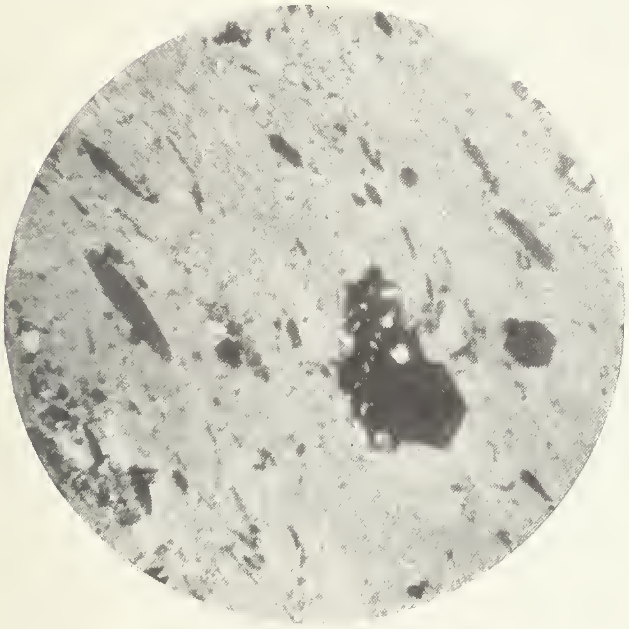

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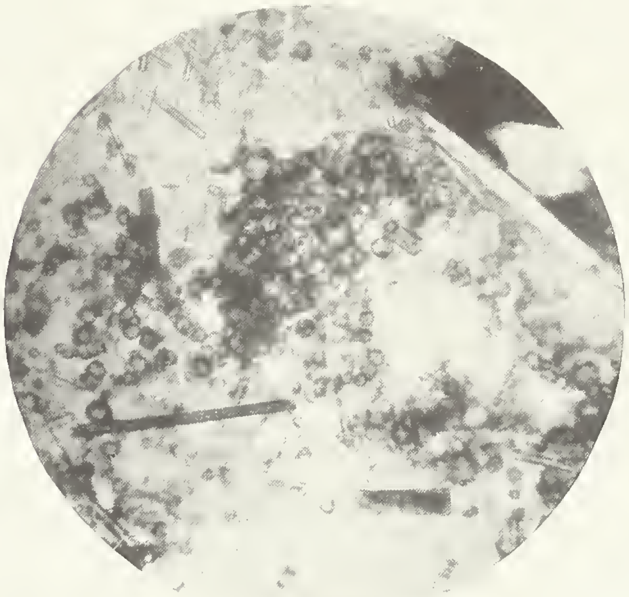

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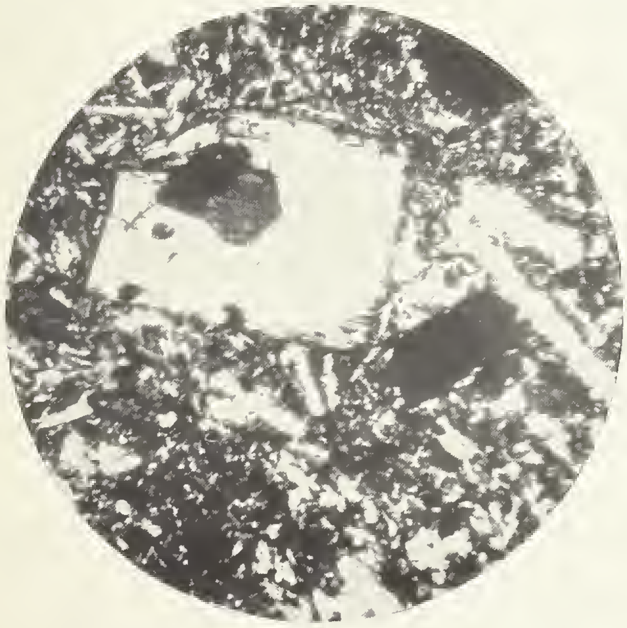

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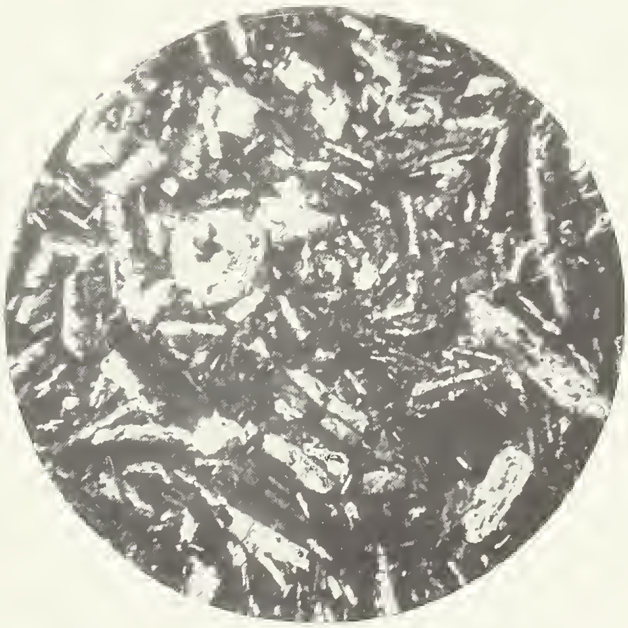
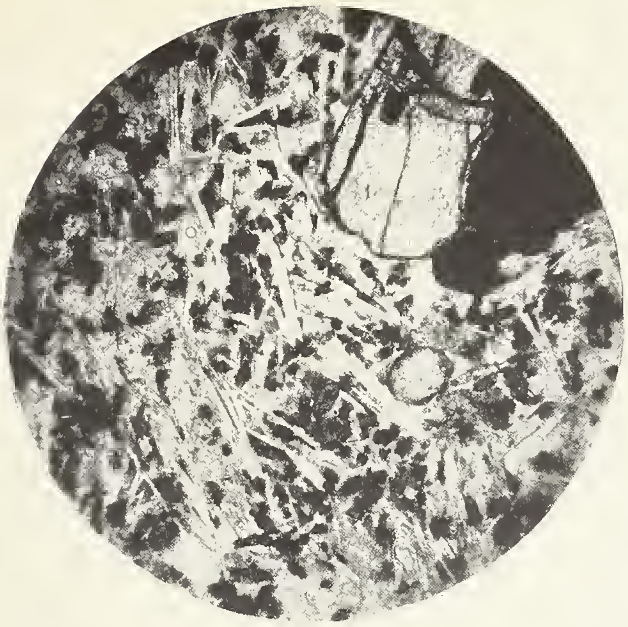


Fig. 6

D. L. Williams, B.M. (Nat. Hist.), photo.

PHONOLITIC TRACHYTES AND TRACHYTOID PHONOLITES
FROM THE ROSS ARCHIPELAGO



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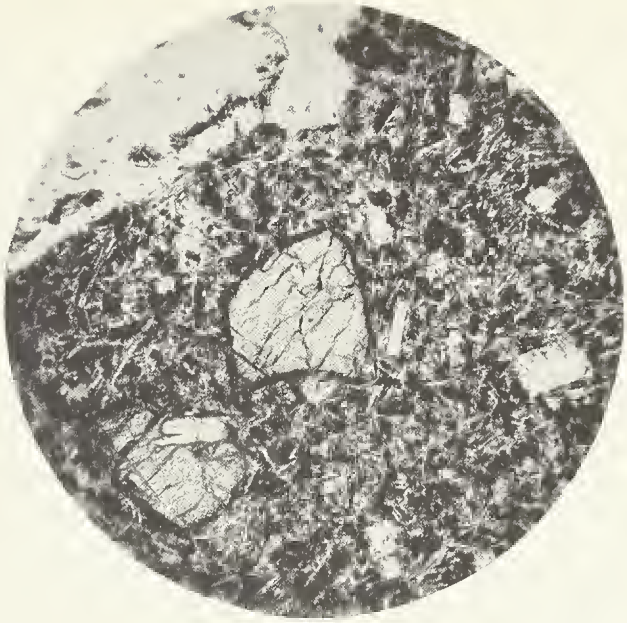

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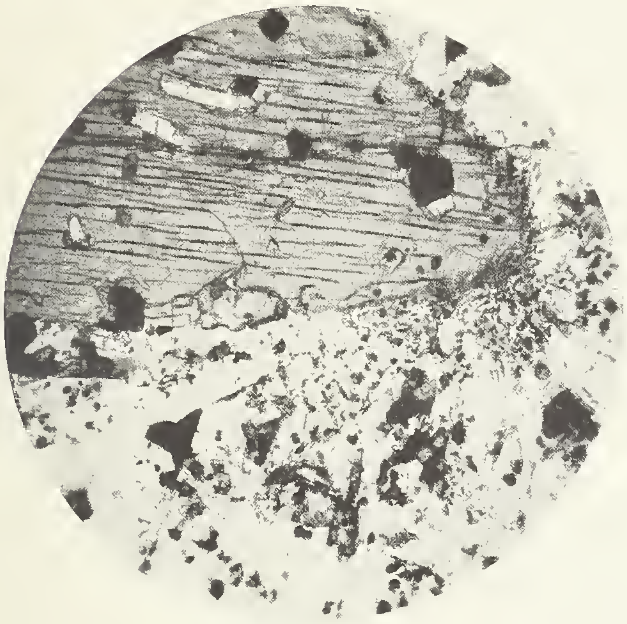

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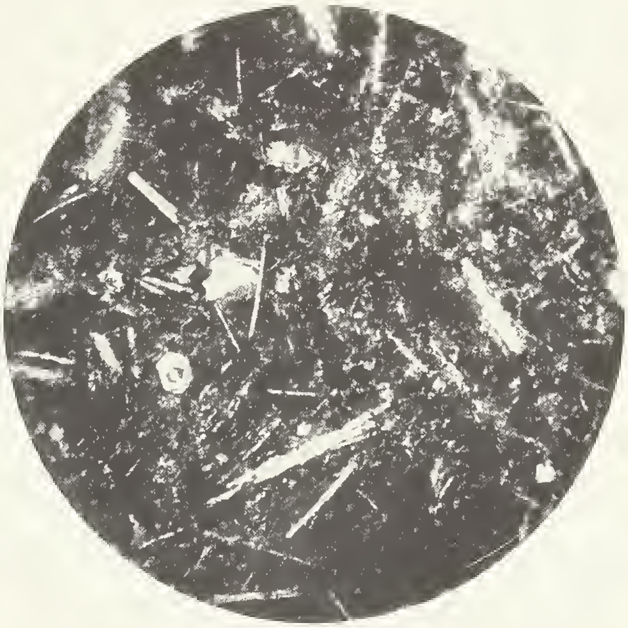

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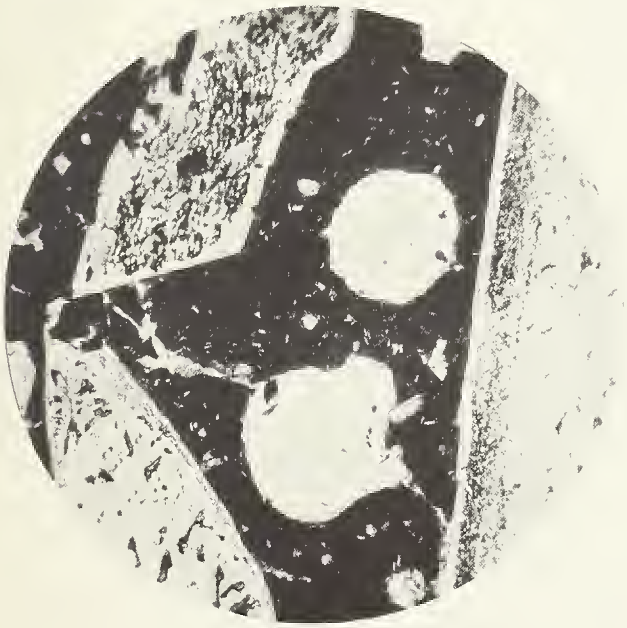

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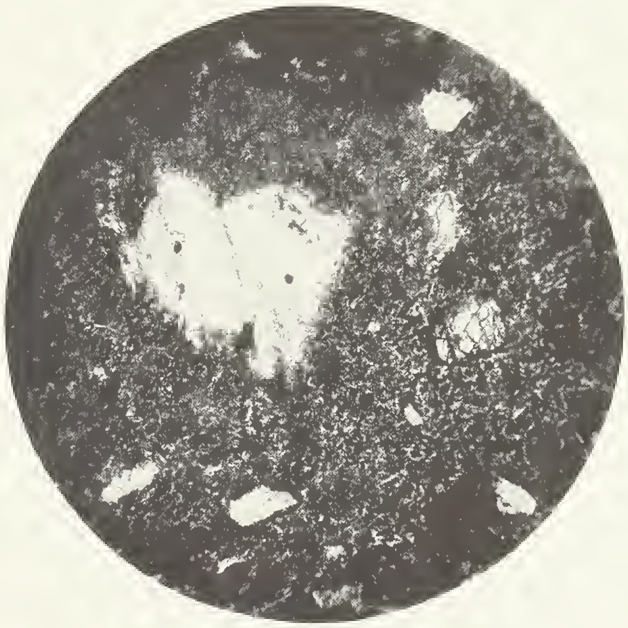
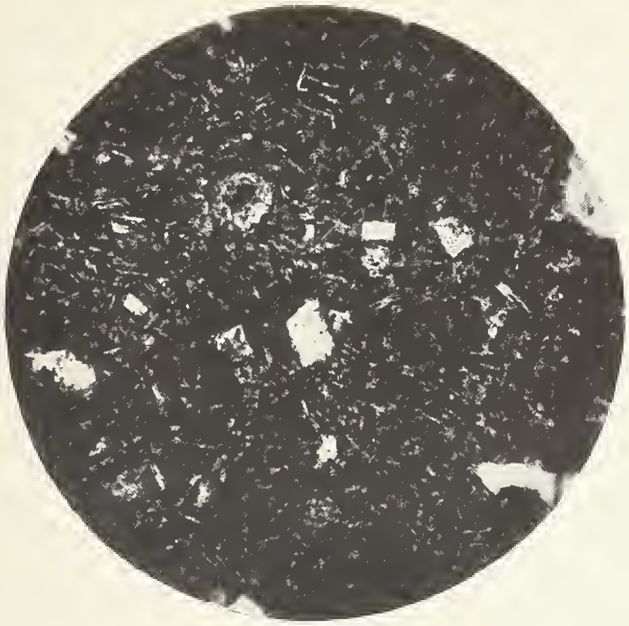


Fig. 6

D. L. Williams, B.M. (Nat. Hist.), photo.

KENYTES FROM THE ROSS ARCHIPELAGO



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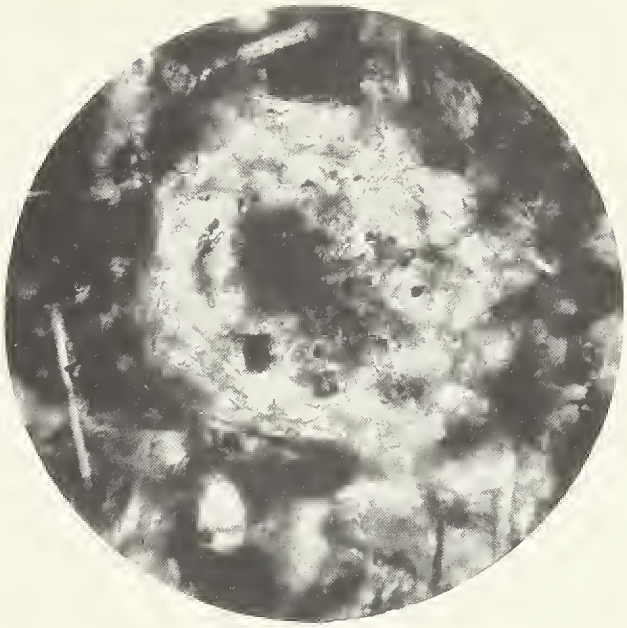

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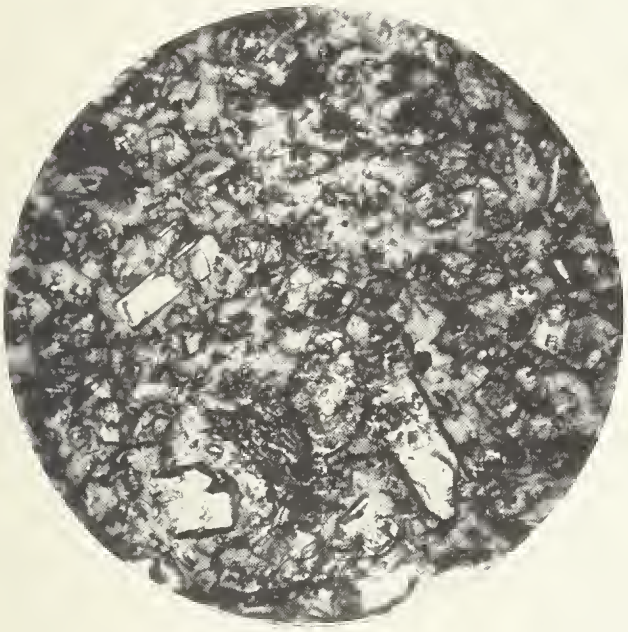

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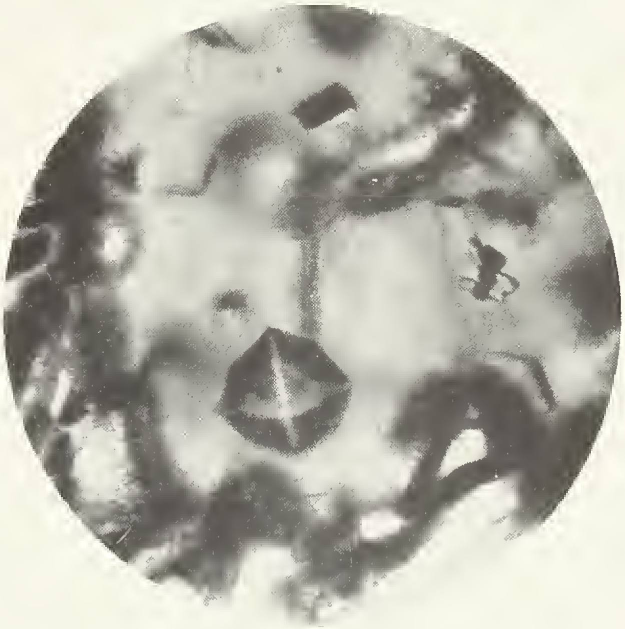

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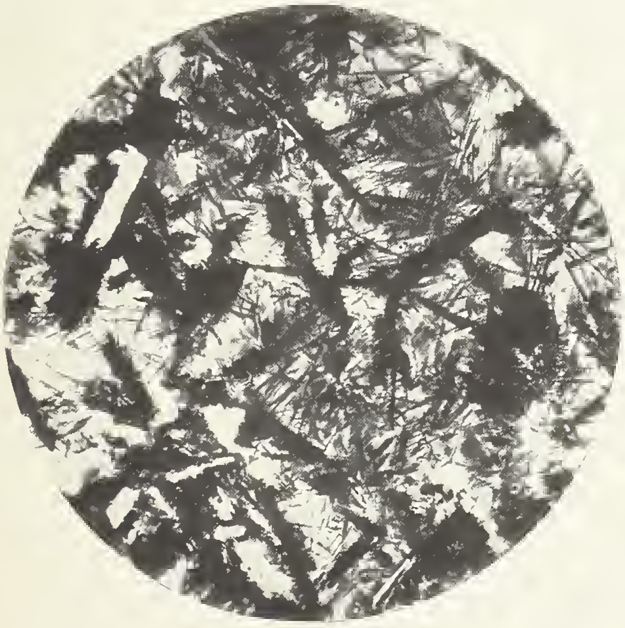

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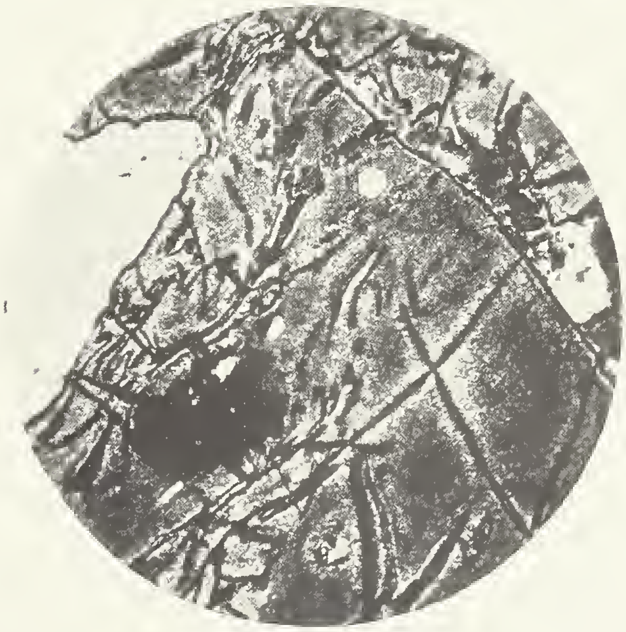
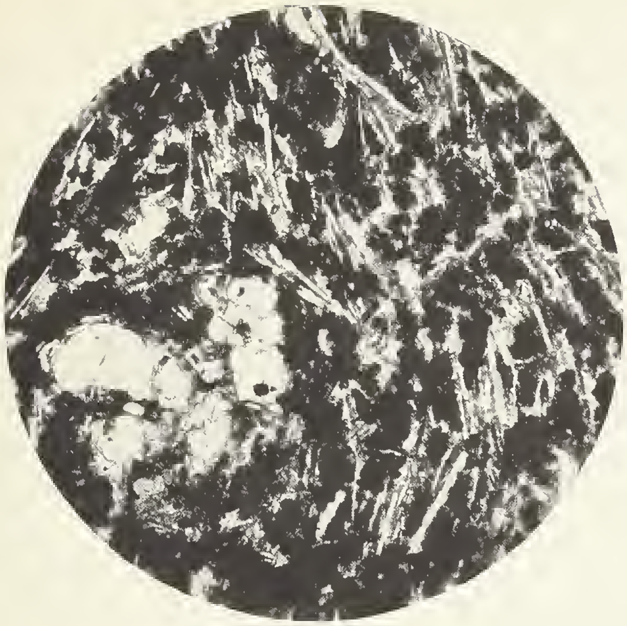


Fig. 6

D. L. Williams, B.M. (Nat. Hist.), photo.

KENYTES FROM THE ROSS ARCHIPELAGO



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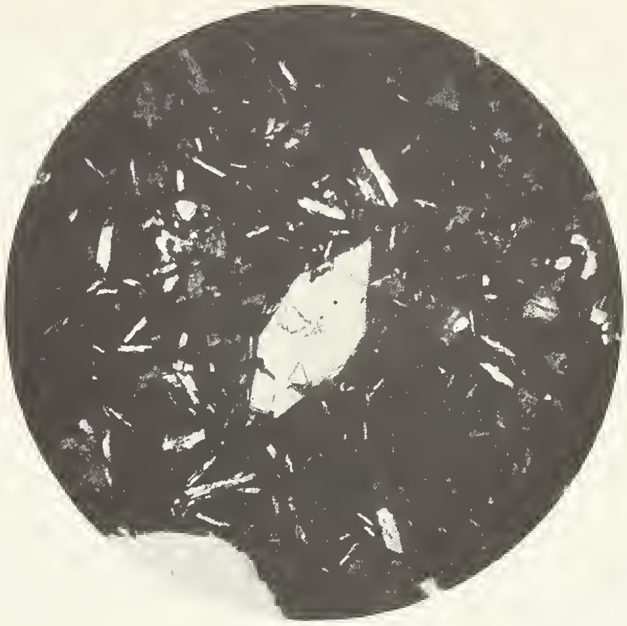

Fig. 2

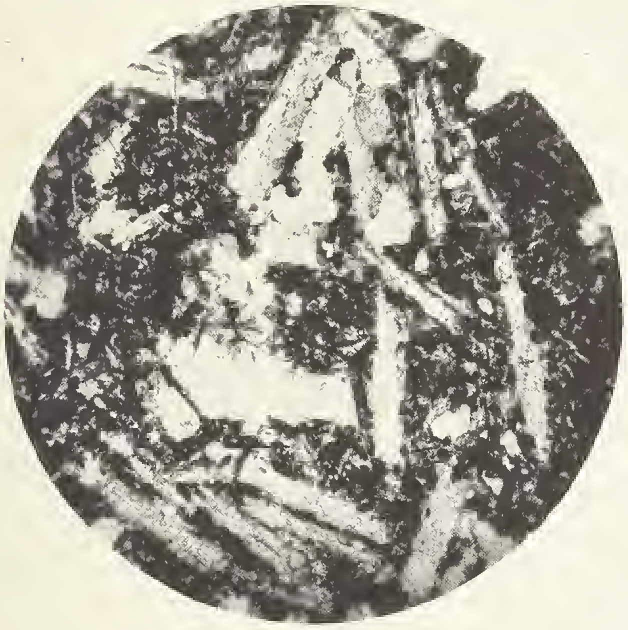

Fig. 3

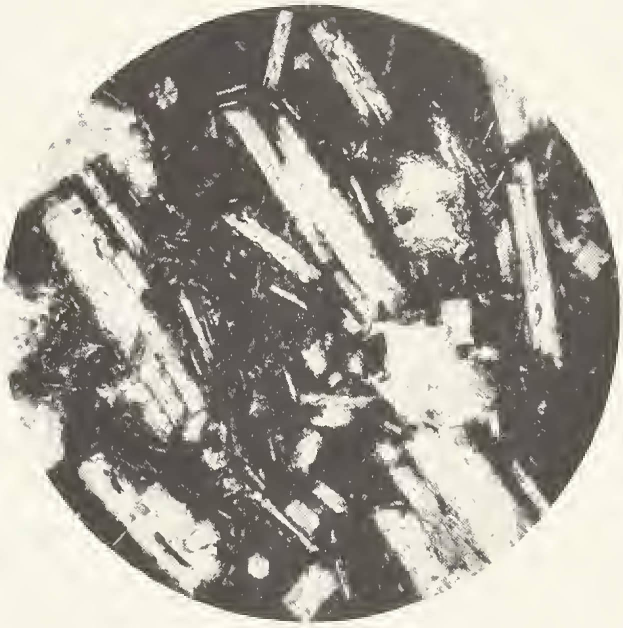

Fig. 4

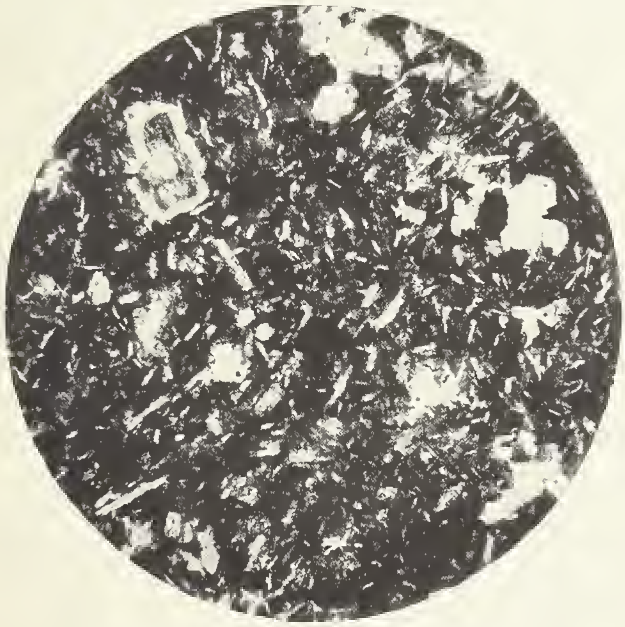

Fig. 5

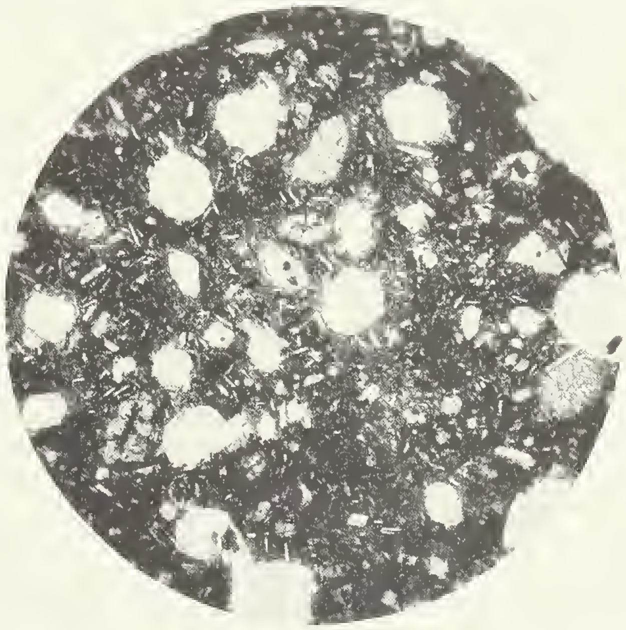

Fig. 6

D. L. Williams, B.M. (Nat. Hist.), photo.

BASALTS FROM THE ROSS ARCHIPELAGO
AND FROM THE MAINLAND, SOUTH VICTORIA LAND

BRITISH MUSEUM NATURAL HISTORY
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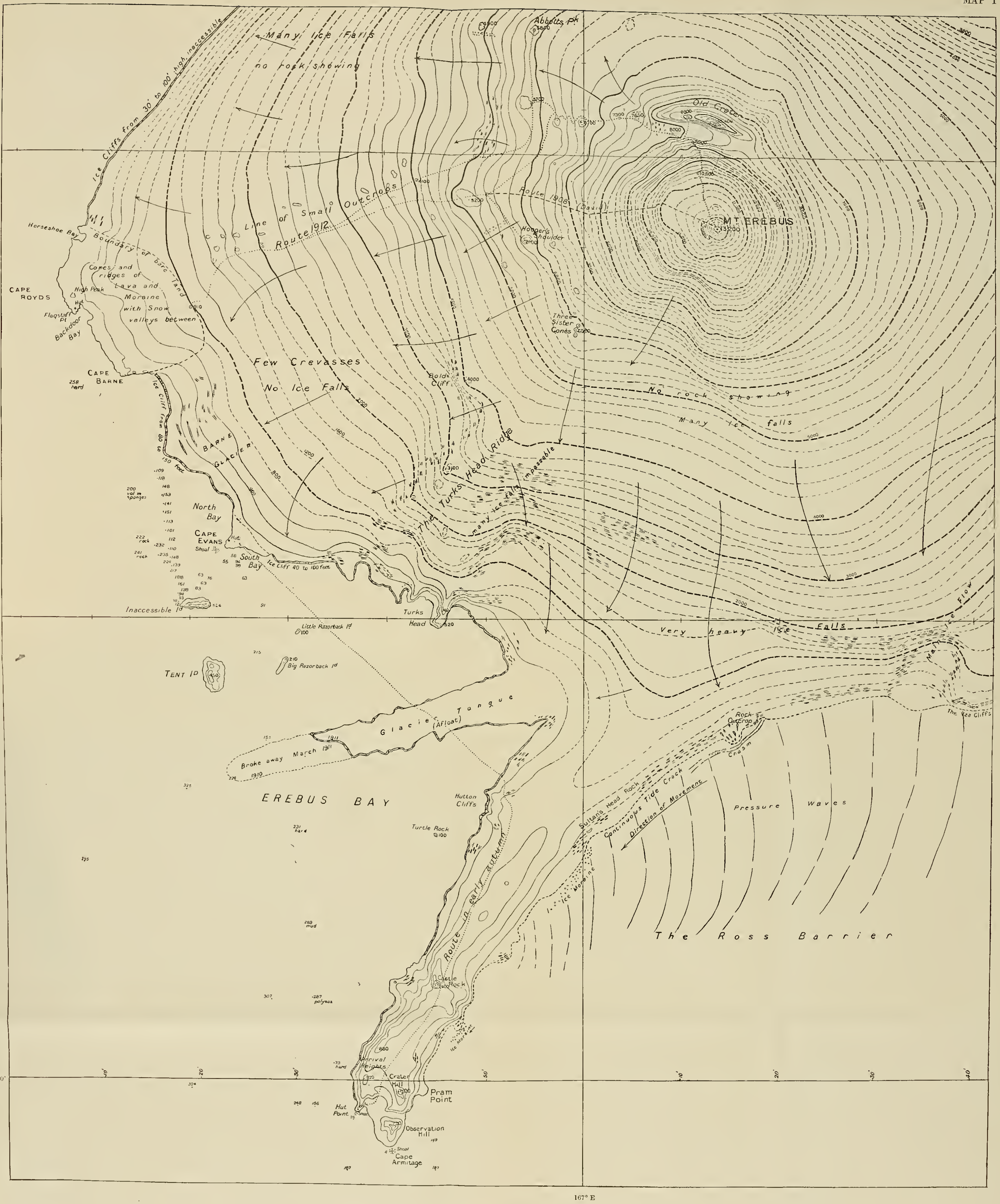
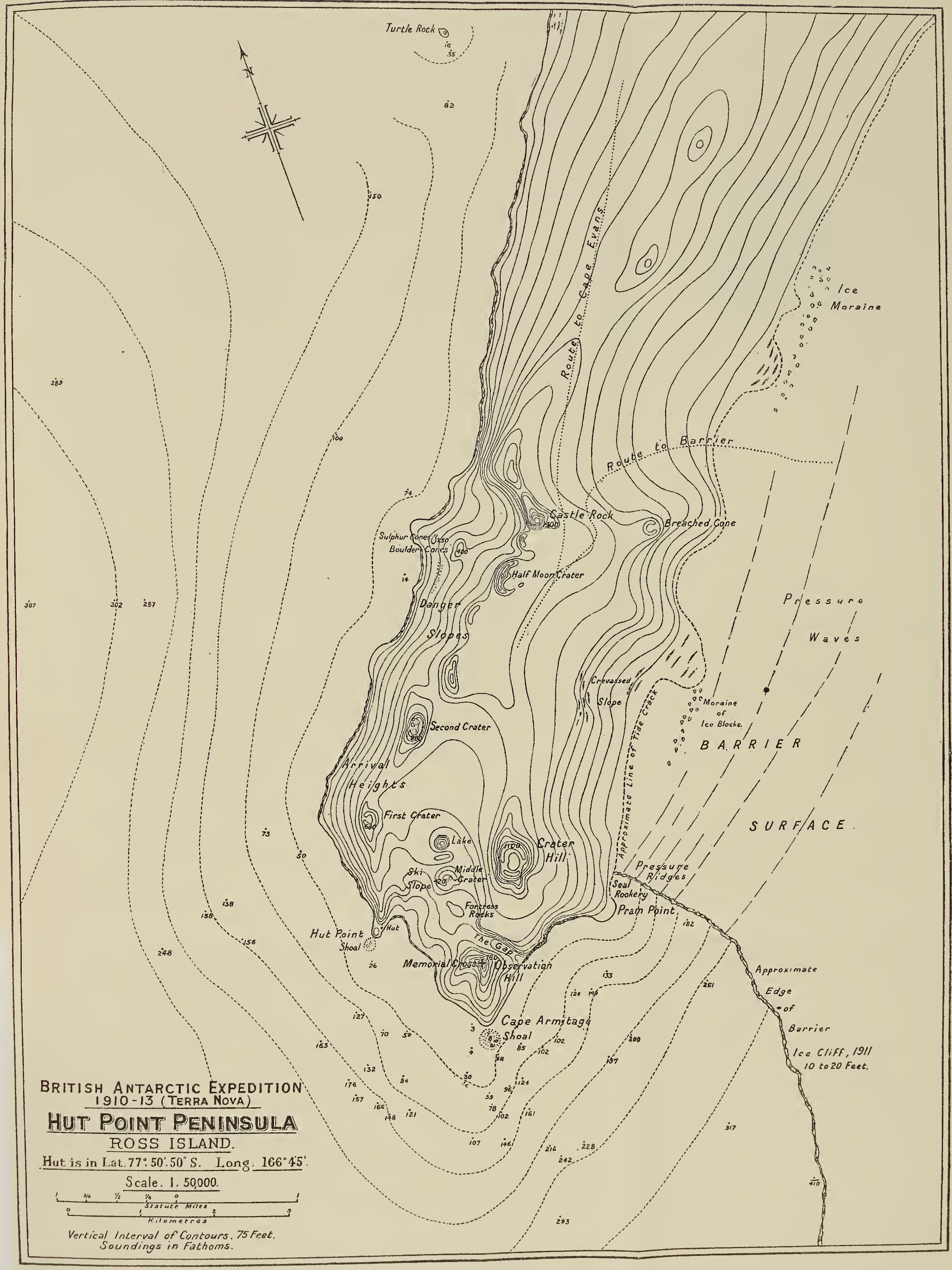
MAP I



MAP OF ROSS ISLAND, WEST COAST

Copied from British (Terra Nova) Antarctic Expedition, 1910–1913.
The Physiography of the Ross Archipelago. By Frank Debenham, O.B.E.

Scale – 1 : 100,000 Contour interval 200 feet


Turtle Rock
16
35
N
82
150
289
100
74
Sulphur Cones 1250
Boulder Cones 1400
14
Castle Rock 1400
Breached Cone
Half Moon Crater
Route to Cape Evans
Route to Barrier
Ice Moraine
Danger Slopes
Pressure Waves
Crevassed Slope
Moraine of Ice Blocks
BARRIER SURFACE
Approximate Line of Tide Crack
Second Crater 880
Arrival Heights
First Crater 630
Lake
Crater Hill 1100
Ski Slope
Middle Crater 420
Fortress Rocks
Pressure Ridges
Seal Rookery
Pram Point
182
Hut Point
Hut
Shoal
The Gap
Memorial Cross
760
Observation Hill
Cape Armitage
Shoal
Approximate Edge of Barrier
Ice Cliff, 1911 10 to 20 Feet.
307
302
287
73
50
138
136
156
248
26
133
124
149
261
127
70
59
3
8
85
102
102
200
197
163
132
84
30
124
96
176
157
166
148
121
59
78
102
161
317
107
146
216
228
242
410
293
BRITISH ANTARCTIC EXPEDITION
1910-13 (TERRA NOVA)
HUT POINT PENINSULA
ROSS ISLAND.
Hut is in Lat. 77° 50' 50" S. Long. 166° 45'.
Scale. 1. 50,000.
1 3/4 1/2 1/4 0 1
Statute Miles
0 1 2 3
Kilometres
Vertical Interval of Contours. 75 Feet.
Soundings in Fathoms.

BRITISH MUSEUM (NATURAL HISTORY)

BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910

NATURAL HISTORY REPORT

GEOLOGY. VOL. II. No. 2. Pp. 109—150

THE VOLCANIC ROCKS OF CAPE ADARE SOUTH VICTORIA LAND

BY

W. CAMPBELL SMITH

WITH TWO FIGURES IN THE TEXT AND THREE PLATES

LONDON:
PRINTED BY ORDER OF THE TRUSTEES OF THE BRITISH MUSEUM
Sold by B. Quaritch, Ltd., 11 Grafton Street, New Bond Street, W.1;
Wheldon & Wesley Ltd. Lytton Lodge, Codicote, nr. Hitchin; H.M. Stationery Office, York House, Kingsway, W.C.2
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British Museum (Natural History), Cromwell Road, London, S.W.7
1959

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[*Issued April*, 1959.]

THE VOLCANIC ROCKS OF CAPE ADARE, SOUTH VICTORIA LAND

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W. CAMPBELL SMITH

X [illegible]

WITH TWO FIGURES IN THE TEXT AND THREE PLATES

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BRITISH MUSEUM
20 APR 1959
NATURAL HISTORY

Printed in Great Britain under the authority of Her Majesty's Stationery Office by
William Clowes and Sons, Limited, London and Beccles. Wt. P.67280. K.4.

I. INTRODUCTION

The first landing at Cape Adare was made in 1894 by an Australian of Norwegian birth, Carstens Borchgrevink, who had signed on as a member of the crew of the whaler *Antarctic* under Captain Lars Kristensen. A few specimens of the rocks were collected at that time but a more extensive series was obtained in 1898 when Borchgrevink returned to Cape Adare in the *Southern Cross* leading an expedition sponsored by Sir George Newnes. Borchgrevink's expedition was the first to winter on the Antarctic Continent. In the collection of geological specimens he was assisted by Lieutenant Colbeck and by Mr. Louis Bernacchi.

Specimens collected on Borchgrevink's first landing were described by T. W. Edgeworth David, W. F. Smeeth, and J. A. Schofield, and those obtained on the later Southern Cross Expedition were described by G. T. Prior. Most of the specimens were poorly localized but, assisted by the recollections of Colbeck and Bernacchi, Prior was able to give in rough outline a picture of the geology of the region.

Cape Adare itself was shown to consist of volcanic rocks, mostly basalts, while a formation of pale green slates and quartz-grits constituted the main mass of Duke of York Island in Robertson Bay and the same formation occurred also on the neighbouring mainland, Geikie Land, and extended along the coast towards Cape North. There was no very definite observation on the nature of the junction between the volcanic rocks and the slates, but Bernacchi had reported seeing such a junction some two miles south of Duke of York Island and he had formed the impression that the basalt had flowed over the sedimentary formation and hidden its southerly prolongation (Prior, 1902, p. 331). Bernacchi also reported having seen slates at the foot of Mount Melbourne in Newnes Land but this observation has not been confirmed by the later expeditions (see below).

A landing was made on Cape Adare by Sir Ernest Shackleton with H. T. Ferrar and other members of the Discovery Expedition in 1902 and Ferrar, the geologist, gave a brief description of the Cape and details of two sections across the basalts and tuffs in his report (1907, p. 18). Ferrar thought the volcanic formation formed also the high coastal cliff between Cape Adare and Cape Jones, 150 miles to the south, opposite Coulman Island, and basalts appeared to be developed at the base of Mount Melbourne still further to the south*. Prior examined the specimens collected by the Discovery Expedition but did not describe them, as he found them to be quite similar to those already described by him from Cape Adare, Coulman Island, and Franklin Island collected on the earlier expedition.

---

* Basalt crags near Mount Melbourne are shown in an illustration in *Antarctic Adventure* by R. E. Priestley (1914, p. 206) and the position of Mount Melbourne is shown in map 2 in the same book. It is not certain that these basalts belong to the same volcanic series as those of Cape Adare and Coulman Island.

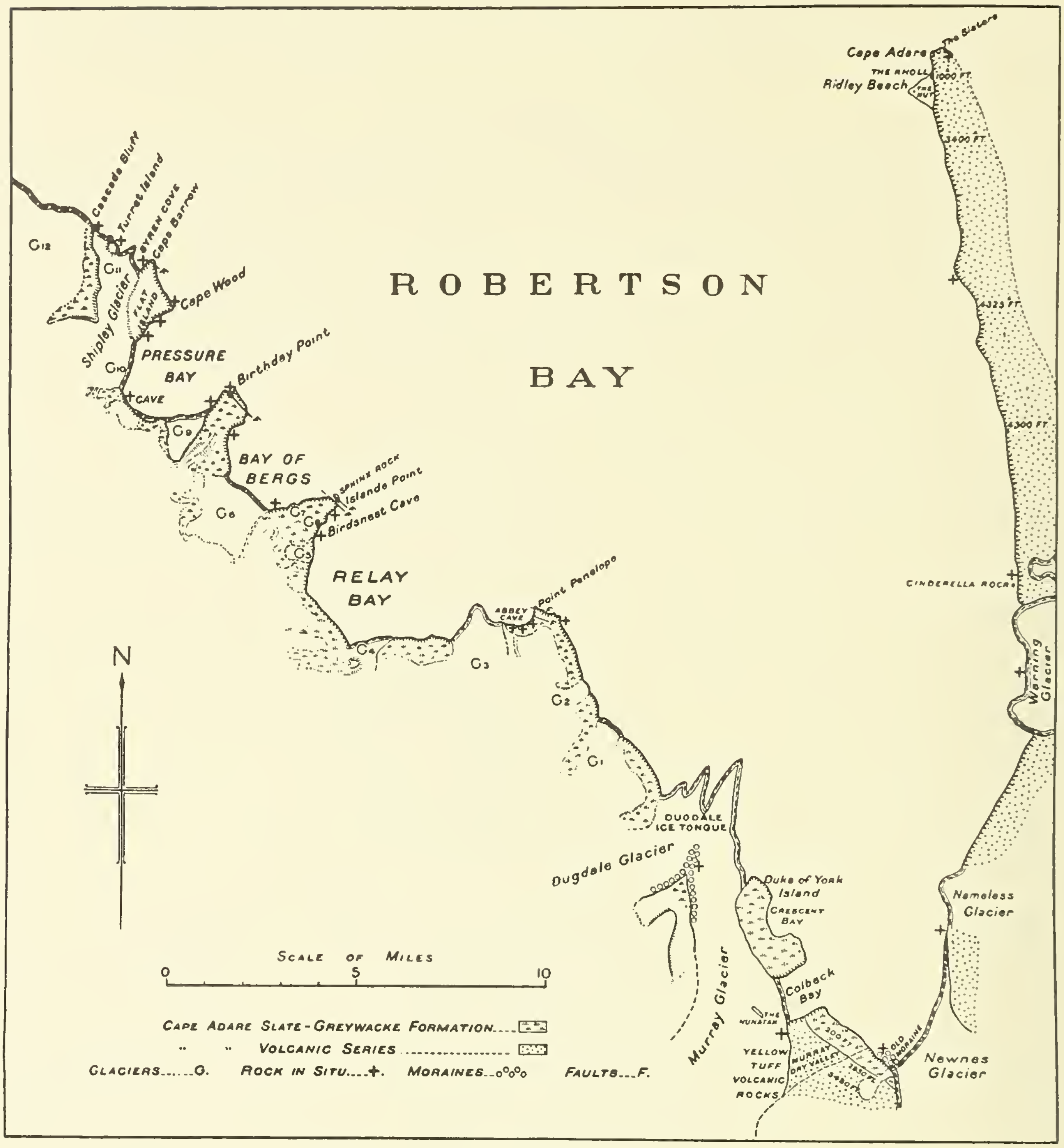

Fig. 1. Map of Robertson Bay Region.

This was the sum total of the knowledge of the geology of Cape Adare and Robertson Bay when the six men of the Northern Party landed from the *Terra Nova* on 18 February 1911. They established themselves on Ridley Beach, a triangular patch of beach, close under the cliffs and about a mile across at its base. Here they built their hut, not far from the old one left by Borchgrevink, and from this base they investigated the physiography and glaciology, kept regular meteorological records, and collected rocks from every accessible outcrop and from the moraines of the glaciers at the end of Robertson

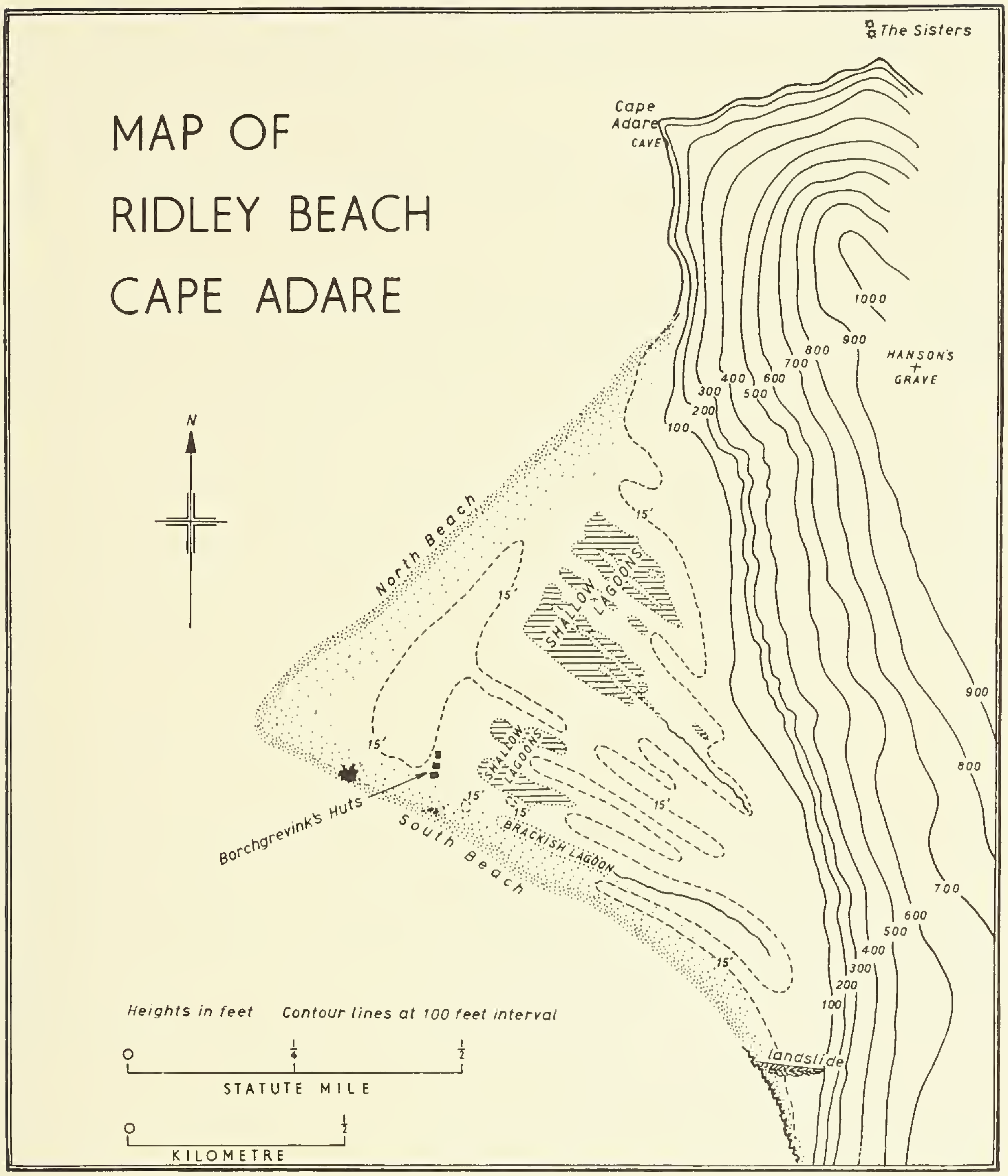

Fig. 2. Map of Ridley Beach.

Reproduced by kind permisson from the inset map II in R. E. Priestley's Memoir on the Physiography of Robertson Bay and based on the plane-table survey by Commander V. L. A. Campbell, D.S.O., R.N. (see Plate 1, fig. 3).

Bay as well as from the beach itself. They remained at Cape Adare until 4 January 1912, having lived there almost a whole year.

The story of the life and the journeys of the Northern Party has been told by Priestley in *Antarctic Adventure* and the results of his work on the physiography and the glaciology have been published in two reports of the scientific results of the Terra Nova

Expedition. *Antarctic Adventure* and the memoirs are all well illustrated by photographs taken by Staff-Surgeon G. Murray Levick, R.N. and Priestley and some of these show very clearly the outcrops and the cliffs where the geology of the rocks *in situ* has been studied.

The sedimentary rocks have been described in a report by R. H. Rastall and R. E. Priestley published in 1921 and the present report contains a description of all the volcanic rocks.

Most attention has naturally been paid to the rocks collected *in situ* but there are also included brief descriptions of the volcanic rocks from the moraines of the Newnes and Murray Glaciers, of erratics from the top of the Cape, and, in so far as they are notably different from others described, of pebbles and cobbles from Ridley Beach. Less attention has been paid to the beach pebbles than to fragments of rock from the moraines, as Priestley has pointed out that at least four sources, in addition to the cliffs of Cape Adare, have contributed to the beach material. These sources are: (1) erratics from the surface of the plateau about 800 feet above sea-level on the Cape itself, left by some former source of land ice; (2) exposures of rock further south along the coast of the mainland; (3) material left by stranded floes and icebergs; and (4) moraine material from a great glacier that may once have filled Robertson Bay to a great depth, possibly over a thousand feet above present sea-level (Priestley, 1923, p. 6).

Priestley's account of the physiography of the region contains information on the distribution of volcanic and sedimentary rocks and the available information is shown on a map accompanying the report on the slate-greywacke formation (1921, fig. 8, p. 122). In *Antarctic Adventure* there are several descriptions of outcrops both of the volcanic rocks on the Cape and of the sedimentary rocks, reached, often with great difficulty, during the spring and summer sledging trips of 1911 (see Fig. 1, p. 112).

Of Cape Adare itself Priestley wrote: 'It is composed in the main of a series of almost horizontal, slightly northward-dipping sheets of basalt lava which are, however, interspersed with much more irregularly-shaped and disposed bodies of agglomerate and tuff, and which are pierced through with numerous dykes and, probably, with less numerous volcanic necks' (1923, p. 8).

Specimens in the collection of scoria, volcanic 'bombs', and masses of ropy lava seem to indicate the former presence of a centre of eruption quite close to Cape Adare.

Volcanic rocks, therefore, are seen to compose the whole of the Cape but west of the Cape they are absent in Robertson Bay.

That the volcanics rest on a basis of the slate-greywacke formation is deduced by Priestley from 'the occurrence of scraps of slate and quartzite in the Cape Adare tuffs' (1923, p. 18), and other evidence of this has been yielded by the study of xenoliths in some of the basalts (see p. 120).

Accessible outcrops where sedimentary rocks and basalts or tuffs are in contact are evidently very few. One such junction, as reported above, was seen by Bernacchi south of Duke of York Island, and Priestley records one 'on the most southerly bluff of all' in Robertson Bay 'where the basalt of the Cape Adare series cuts across the sediments in a dead straight line, with features suggesting a fissure eruption on a small scale' (1921, p. 124).

The distribution of basalt and of sedimentary rock in the moraine of the Newnes Glacier and of a tributary has an interesting bearing on the history of the glacier (Priestley, 1923, p. 18) and Priestley was able to make some observations on the relative positions of basalt and sediment on the hills bordering this glacier. Basalt cliffs line the cwm within which the head of the tributary glacier lies (1923, p. 15) and in the course of a painful climb up the hills on the right (west) of the Newnes Glacier Priestley and Dickason found basalt within 700 feet of the top of the hill, there 3,600 feet, and before reaching the basalt they had found green quartzite cropping out above the rubble of the screes and dipping steeply towards the south-west (Priestley, 1914, p. 179).

Such information as there is on the geological structure of the region is discussed in the report on the slate-greywacke formation (1921, p. 123), and Priestley has given reasons for concluding that the main coastal fault-plane, known to be of great importance in the McMurdo Sound region, continues through the Robertson Bay region and on to the north (1923, p. 18).

II. VOLCANIC ROCKS *IN SITU* ON THE CAPE

Olivine-Basalts

Apart from the tuffs and agglomerates referred to in Priestley's description of the Cape the volcanic rocks collected *in situ* are, with the exception of a few specimens from one very restricted locality, all olivine-basalts.

These can be divided on their characters as seen in hand-specimens into three types as follows:

A. Black, glassy, aphanitic olivine-basalt;
B. Dark grey, holocrystalline olivine-basalt; and
C. Porphyritic olivine-basalt with insets of augite and olivine.

The basalts of the second type contain abundant xenoliths of quartzose rocks, and small xenoliths of similar rocks are occasionally seen also in the black glassy basalt. These xenoliths are of particular interest as they afford evidence of the rocks through which the basalts were extruded.

A. Black, glassy Olivine-basalt

This type is best represented by a specimen [432] from an exposure 100 yards north of the northern limit of the snow drift on Cape Adare. Other specimens belonging to the same type, listed in the order in which they are described, are: 426 labelled only Cape Adare; 229 from 300 feet up on the Cape; 246 from the scree; and 247 part of a 'bomb'.

The hand-specimen of 432 is dark neutral grey, compact, aphanitic, and shows only a few small circular vesicles less than 0·5 mm. in diameter. Under a hand-lens on a smooth surface extremely small laths of feldspar can just be distinguished in the dark base. Under the microscope it is seen that the main crystalline constituent is plagioclase feldspar in lath-shaped crystals ranging in size from crystals measuring 1·5 × 0·3 mm. down to microliths in the groundmass 0·007 mm. across. The general impression of the rock, as seen in thin section, is of abundant plagioclase laths and micro-insets of olivine and, less abundant, augite in a brownish glassy groundmass containing slender feldspars, augite prisms, very small olivines, and cubes and 'dendrites' of opaque 'ore' (assumed to be magnetite). The colour of the glass in thin section is deep brownish drab.

The feldspars show Carlsbad and albite twins. Extinction angles measured indicate a composition near An_{67}.

The microliths are a more acid labradorite near An_{52} perhaps ranging up to An_{56}. The olivine of the micro-insets is colourless but stained brown along fissures. The average size for the micro-insets is about 0·25 × 0·17 mm. but crystals of olivine in the groundmass are very small, only about 0·05 mm. across (Plate 2, fig. 1).

The augite is optically positive, 2V moderate, $c{:}\gamma$ near 45°. Micro-insets show faint zoning, the colour in thin section ranging from light vinaceous fawn in the outer shell to pale vinaceous fawn in the core. The groundmass pyroxene is similar in colour to the outer zones of the micro-insets. Though fewer in number than the olivine micro-insets the augites are the larger in size, averaging about 0·75 × 0·2 mm. It is noticeable that the augites sometimes form small radiating groups of twinned prisms.

The other constituent of the groundmass, in addition to the plagioclase, augite, olivine, and glass, is magnetite. This forms small cubes (0·004 to 0·025 mm.). Small combs of dendritic black 'ore' that may be ilmenite are seen under high magnification in the brown glass.

One black glassy basalt of this type [426] shows occasional crystals of brown hornblende, either xenocrysts or insets, similar to the hornblendes in the porphyritic olivine-basalt described below, Type C. (p. 118).

Another example [229] from 300 feet up on Cape Adare is dull, and dark neutral grey in colour and has a dense black glassy base. It lacks the glassy lustre of the other specimens referred to this type. It is somewhat vesicular and some of the vesicles at or near the surface are lined with an opaque white deposit and some contain opaque white crystals. Further reference will be made to these below (p. 122). The surface of the specimen shows ropy structure, indicating that it formed part of a lava flow.

Under the microscope this rock is seen to consist of abundant small, stout laths of labradorite (near An_{66}) with few, small crystals of brown altered olivine and still smaller augites in a dense black glassy base. The proportion of feldspar crystals to glass is about three to five.

A specimen which may represent a holocrystalline equivalent of Type A is 246 from the scree on Cape Adare. The habit of its plagioclase laths and of the very small micro-insets of olivine (here all altered to 'iddingsite') and of augite is similar to the more glassy basalts of this type described above, but the groundmass minerals, plagioclase, augite and magnetite, and acicular inclusions, are in a colourless birefringent base which may be either feldspathic or nepheline. In any case the interstitial base is very small in amount. This specimen is brownish drab in colour. It contains many nearly spherical vesicles, rarely exceeding 1 mm. in diameter, lined with white zeolites, partly isotropic analcime.

A 'bomb' [247] with a black, glassy vesicular outer surface consists of lava of the same type as those here described. Another 'bomb' [253] 'from agglomerate on the road' is very dense and fine-grained and appears to belong to lava of a different kind.

B. Dark grey holocrystalline Basalt

This is represented by a large number of specimens from several localities designated in Priestley's notes as follows:

1. Below the Survey Rock	254, 255, 256, and 258
2. Knoll a little below and a little north of the black Survey Rock	261 to 329
3. Bluff near the end of the upper beach platform .	383 to 425
4. Depot exposure	456 and 460
5. Bluff south of the Depot exposure . . .	468
6. Foot of cliff between Depot exposure and Solitary Rock	477 to 486
7. Exposure one to two hundred yards south of Solitary Rock	522, 527, 530, 543, 544, 545

These dark grey basalts are all vesicular and appear much less fine-grained than the black glassy basalts described above. The colour of most of them is deep neutral grey, sometimes weathering to light purplish grey and deep olive-grey in the vesicles. The vesicles are usually empty, except that some are partly coated with a white powdery substance of the same kind as that found coating patches of the surface of some of the specimens and lining vesicles in the Type A basalt described above.

A rather fine-grained vesicular example of this basalt [485] from the foot of the cliff between Depot exposure and Solitary Rock is seen in thin section to consist of great numbers of slender laths of plagioclase (0·15 × 0·01 mm.) in a dark base with micro-insets of pale buff augite up to 0·4 mm. long and occasional micro-insets of plagioclase. In one specimen [460] augite also appears as insets up to 2 mm. across. Small magnetites (0·1 mm.) occur as micro-insets as well as abundantly in the dark base. The groundmass between the feldspar laths consists of granular augite and magnetite as small cubes (0·01 mm.) and finer dust, and some colourless, birefringent base with refractive index apparently below that of the plagioclase. Some small brown altered olivines are observable and more may be hidden by the magnetite-rich dark base.

The specimens from the bluff near the end of the upper beach platform have a holocrystalline groundmass. They contain small insets of augite, about 1 mm. across, but these are few and inconspicuous. There are occasional idiomorphic insets of colourless olivine, up to 1·5 mm. long with narrow brown edges to the colourless crystals. The groundmass consists of slender laths of plagioclase, augite, brown altered olivine, and magnetite, all lying between the feldspar laths in a base of a colourless mineral of low birefringence containing more small feldspar microliths. The texture thus approaches that usually described as intergranular (Plate 2, fig. 2).

The feldspar laths are very thin, about 0·02 mm. across, and are up to 0·3 mm. long. They show Carlsbad and albite twins in which symmetrical extinction angles give a maximum of 28°, indicating labradorite near An_{52}.

The augite insets, pale vinaceous fawn in thin sections, show 'hour-glass' structure. One inset gave extinction angles $c{:}\gamma = 49°$ in the shell and 53° in the core. Others gave readings ranging from 43° to 50°.

The interstitial colourless mineral in the base is alkali-feldspar. There are in it small dark brown inclusions and minute colourless needles.

C. *Porphyritic Olivine-basalts with insets of Augite and Olivine*

This type is represented at Cape Adare mainly by specimens from a pseudo-cave, a circular depression in the cliff produced by atmospheric weathering, not far from Borchgrevink's Depot.

Typical hand-specimens of this rock [245, 249] are dense, black, with a glassy lustre and smooth, subconchoidal fracture. One specimen [357] shows many round pale neutral grey spots, the familiar spotty weathering, freckling, or 'Sonnenbrenner', frequent in basalts of this kind in other regions. An extreme porphyritic example of this type [431] contains numerous insets of both augite and olivine up to 8 mm. across. Smaller black augites and brown olivine crystals, 2 to 3 mm. across, are visible in most specimens. The groundmass is aphanitic and neutral grey. Vesicles are usually few. At a rough estimate the insets occupy about 25 per cent by volume of the rock.

Another example [234] contains very abundant fresh, reed-yellow to olive-yellow olivines. This rock has augite insets also but these contain inclusions of opaque groundmass or glass and they then merge so closely with the groundmass that they are hardly distinguishable on the rock surface even with a hand-lens.

Under the microscope it is seen that in addition to the augite and olivine there are in some of these porphyritic basalts insets or xenocrysts of brown hornblende usually in the process of resorption [431, 248]. One specimen [249] contains also a group of tabular labradorite crystals. Apart from this plagioclase has not been observed as insets in any of the specimens from the pseudo-cave.

The hornblende is pleochroic: α' cream-buff, γ' honey-yellow. Absorption $\gamma > \beta > \alpha$. Extinction $c{:}\gamma$ small. The augites are pale vinaceous buff in colour and not appreciably pleochroic: $c{:}\gamma = 52°$. Both olivines and augites range up to 2 to 3 mm. in length.

Magnetite as micro-insets is frequently associated with the augite and olivine. In most specimens the olivines are colourless in thin section but occasionally they show various shades of yellow and frequently have narrow brown altered borders.

The groundmass of a typical specimen of these porphyritic basalts [249] consists of microliths of labradorite, near An_{57}, with small prismatic olivines abundant in a base of fawn-coloured glass with very small augite microliths and magnetite cubes (0·004 mm.). A notable feature is the unusual abundance of small olivine crystals in the groundmass. They are about the same size in cross-section as the feldspars, ranging from 0·02 to 0·007 mm., and generally prismatic in habit. Many of them are hollow at the ends or have cavities filled with groundmass. In some specimens they are all altered to brown iddingsite, and in these cases they do not show the skeletal habit.

Variations in the groundmass are shown by several of the specimens. Some have the groundmass more dense, the magnetite being very abundant, and both feldspar microliths and magnetites are very small, ranging in cross-sections from 0·017 to 0·002 mm. Part of the colourless base of the groundmass in 241 is weakly birefringent and may be alkali-feldspar. In 244 there is a strong tendency to parallel alinement of the feldspar laths, and the groundmass between the feldspars is glass, vinaceous buff to fawn in colour, with abundant granular augite and magnetite. There is less olivine visible in this case. A specimen [676] in which the groundmass is better crystallized and slightly coarser grained than in the specimens from the pseudo-cave was broken off, almost certainly *in situ*, by G. P. Abbott, from 1,000 feet up on the Cape. It shows small brown olivines and black augites, 2 to 4 mm. across, in a dense, dark neutral grey groundmass. (See also p. 138 and Plate 2, fig. 6.)

Other examples of lavas of this type are seen in a basalt-tuff and in a specimen of ropy lava referred to above. In this ropy lava the olivine insets show remarkable black inclusions, presumably of magnetite, almost completely obscuring the original olivine. These are perhaps the result of reheating of the insets in the surface lavas. David, Smeeth, and Schofield described and figured similar olivine insets 'traversed by a dense rectangular network composed of strings of magnetite grains' from an olivine-basalt from Cape Adare collected by Mr. C. E. Borchgrevink in 1894–5 (1896, p. 478 and pl. 13, fig. 4). Something of the same kind has been described by I. D. Muir and C. E. Tilley in picrite-basalts from Kilauea, Hawaii (1957, p. 247).

Another basalt from the agglomerate in the pseudo-cave showing scattered small augites, 1 to 2 mm. across, in an aphanitic, dark neutral grey groundmass shows some differences from the other porphyritic basalts described from this locality. It contains resorbed hornblende insets as well as augites but none of olivine were observed. In their optical properties the hornblendes and most of the augites resemble those of the basalts just described but some augite sections show a pale green (glass-green) core in a narrow shell of the usual prevailing buff colour. Magnetite occurs as small micro-insets and apatite appears occasionally as small hexagonal prisms. The groundmass consists of small laths of plagioclase (0·07 by 0·007 mm. and less), small cubes of magnetite, and granules and small colourless prisms of pyroxene in a faintly buff-coloured weakly birefringent base, which, as shown by an HCl etch test, is, at least partly, feldspathoid.

Porphyritic basalts similar to those described above were recorded by G. T. Prior from the collection made on the Southern Cross Expedition [B.M. 85752, 28, 29 and 30] and one [85752, 23] is figured (1902, pl. 53, fig. 5).

It was not known whether these were *in situ*, but Prior was able to match them with a specimen collected by Lieutenant Colbeck 'from a cliff in Robertson Bay, about four miles south of the camp'. According to Lieutenant Colbeck's description 'they occur in small dykes three feet wide, traversing the cliff from top to bottom at various angles' (1902, p. 327).

A similar basalt is probably the 'olivine basalt (No. 7)' collected by C. E. Borchgrevink in 1894–5 on his landing from the whaler *Antarctic* and described by Edgeworth David, W. F. Smeeth, and J. A. Schofield (1896, p. 477). They give a fairly complete description of the rock with particular reference to the augite and olivine insets, and they also made a chemical analysis, quoted in column 1, table I.

Prior was inclined to compare these basalts with those he had examined from Coulman Island [85752, 69–76] and from the foot of Mount Terror, as well as with those from Possession Island collected on the Southern Cross Expedition. He gives a chemical analysis of a hornblende-basalt [B.M. 85752, 93] from the foot of Mount Terror [column 2, table I] but he gave no detailed description of the rock. It contains more xenocrysts of brown hornblende than most of the Cape Adare porphyritic basalts described, and certainly fewer olivine insets. The groundmass has a brown glassy base and is similar to that of the Cape Adare porphyritic basalts, again perhaps with less olivine. Prior's analysis shows very considerable differences from that of the Cape Adare basalt described in David, Smeeth, and Schofield's paper (column 1, table I).

It is worth recording here that a specimen [85752, 101] collected by Mr. Louis Bernacchi on the Southern Cross Expedition, and believed to represent the basalt dike figured in Prior's report on the rock-specimens (1902, p. 327) is a dolerite consisting, as Prior describes it, 'of a medium-grained aggregate of felspar-laths and pale purple augites with only a little magnetite and no interstitial glass'. No rocks resembling this were collected *in situ* at Cape Adare by Priestley.

Xenoliths in the Basalts

Reference has been made above to xenoliths, apparently of sedimentary quartzose rocks, in basalts of Types A and B. In the black glassy basalts, Type A, few xenoliths were seen. They are cream-coloured, compact, and relatively small. From Type B basalts on the other hand large numbers of xenoliths were collected. They are frequently four or five centimetres across and one of the specimens collected by Priestley is 13 cm. in length. These xenoliths show a considerable range of colour from deep greyish olive to brick-red and brown. At exposure 2, near the end of the upper beach platform, the colour ranges from buff to light vinaceous fawn and the edges of the xenoliths adjacent to the basalt are noticeably more pink than in the interior of the xenolith. Penetration of the xenolith by thin stringers of basalt is well shown by some of the specimens.

A good series of thin sections of these xenoliths was examined and some of them were submitted to Dr. S. O. Agrell of the Department of Mineralogy and Petrology at Cambridge and to Dr. A. F. Hallimond for their opinions. Their assistance is here gratefully acknowledged.

TABLE I

	1	2	3
SiO_2	45·13	47·40	or 16·12
TiO_2		0·63	ab 20·96
Al_2O_3	18·13	20·27	an 20·29
Fe_2O_3	12·94	5·38	ne 15·34
FeO		5·48	di 9·06
MnO		0·17	ol 5·63
MgO	7·33	2·94	mt 7·89
CaO	11·23	7·59	il 1·22
Na_2O	2·14	5·78	ap 2·02
K_2O	0·98	2·73	
H_2O+110°	2·18	0·23	
H_2O−110°			
P_2O_5		0·85	
Totals	100·06	99·45	

1. 'Olivine Basalt', David, Smeeth, and Schofield, 1895. Cape Adare.
2. 'Hornblende-basalt', Prior, 1902, II.6.(2)3.4. Foot of Mount Terror, Ross Island. G. T. Prior anal. B.M. 85752, 93. (Basalt in Washington, 1917, p. 577).
3. Norm of 2.

All the inclusions examined contain abundant quartz grains and a few turbid grains of plagioclase were also identified. The grains are subangular and they vary in grain-size from about 0·75 mm. down to less than 0·05 mm. The larger quartz grains are cracked. All give sharp extinction and do not show evidence of strain.

The matrix of these grains is in the main glassy. In thin section it is colourless to pale drab or pale buff. Occasionally it shows small-scale perlitic cracks, and nearly always it is crowded with crystallites. Its refractive index is near 1·508. (Pl. 2, figs. 3–5.)

Two kinds of crystallites are very abundant and both are present in every specimen. The most obvious are slender colourless prisms with straight extinction, positive elongation, and refractive index high relative to the glass.

These properties agree with both mullite and with an orthorhombic pyroxene. At Dr. Agrell's suggestion glass containing these crystallites in abundance was finely powdered and allowed to stand overnight in cold HF. The glass and all the crystallites dissolved, thereby proving that the crystallites are not mullite. They are presumed to be the orthorhombic pyroxene, hypersthene. The other abundant crystallites are cordierite. These are colourless prisms with straight extinction, and negative elongation. Some show hexagonal cross-sections and occasionally sector twinning. The birefringence is low and the refractive index is judged to be near that of quartz.

Dr. Agrell identified tridymite in some cavities in the glass, and there are other crystallites that have not been identified. Some of the xenoliths [126, 127, 131, all from locality 2] contain groups of radiating feldspar laths often clustered in rounded patches and filling apparent druses in the glassy matrix.

Several of the xenoliths show in thin-section opaque rod-like bodies. The central part of these 'rods' consists of a weakly pleochroic prismatic mineral, probably hypersthene, associated with much dusty black 'ore'. The glass in the neighbourhood of these 'rods' is crowded to an exceptional degree with cordierite crystallites which are packed along the sides of the 'rods'. Some of these bodies are bent but most of them are straight and Dr. Agrell has suggested that they represent old fractures in the original sediment infilled with material different in composition to the surrounding rock.

G. T. Prior (1907, p. 105) briefly described sandstone xenoliths in olivine-basalt from Castle Rock on Hut Point Peninsula and somewhat similar xenoliths to those described above were among the numerous inclusions in the phonolitic trachyte of Mount Cis on Erebus described by J. Allan Thomson (1916, pp. 144–145). Two xenoliths of the same kind were found in kenyte at Cape Royds and Sentinel Hill, and Priestley and Debenham both collected similar slaggy inclusions at Mount Cis. They differ in detail from the Cape Adare xenoliths but they agree in their abundance of quartz grains and the nearly colourless glassy base (Campbell Smith, 1954, p. 26).

These xenoliths in the Mount Cis 'trachyte' were explained as inclusions of sandstone and David and Priestley (1914, p. 221) had no doubt that they were derived from the Beacon Sandstone Formation and that this sandstone must lie at depth below the volcanic series of Ross Island. This, no doubt, is the correct explanation of the sandstone xenoliths in the trachyte of Mount Cis on Erebus, but a more likely source for the Cape Adare xenoliths is the greywacke of the slate-greywacke formation of Robertson Bay. These rocks have been described by R. H. Rastall and R. E. Priestley (1921, p. 127). They consist mainly of quartz in angular grains with chips and grains of mudstone and slate, and with some feldspar, and mica in a matrix containing quartz, mica, chlorite, and carbonates. There are no chemical analyses available of these greywackes but their general composition would seem to be such as could supply the hypersthene-cordierite assemblage and the glassy matrix and the abundant quartz grains in the xenoliths in basalt described above.

White Incrustation on Basalts

The white coating on some specimens of the basalts, mentioned above (p. 116) may be several millimetres thick and is sometimes stalagmitic in habit.

Qualitative analysis shows the presence of $Mg^{\cdot\cdot}$ and PO_4''', and an X-ray powder photograph identified the material as the mineral newberyite, $MgHPO_4 . 3H_2O$.

This mineral has been found in caves containing bat guano in Skipton Caves, near Ballarat, Victoria, and in the island of Reunion.* It was identified by G. Richards† on lava collected by R. A. Daly from a cavern in a basalt flow on Ascension Island, and Daly recorded that 'thin deposits of phosphate on the basalt flows occur at many places'.‡ More recently newberyite has been recorded in cracks in fossil mammoths' tusks found buried in clay in Sverdlovsk in the Urals.§

In the occurrences in caves bat guano supplies the phosphate for the newberyite. At Cape Adare it must be derived from wind-blown penguin guano on Ridley Beach. Priestley|| has described how these deposits are carried off each year in the winter gales. The magnesium for the newberyite is presumably supplied by the weathering of the olivine-basalts.

Artificial material with the composition of newberyite is formed by the dehydration of $MgHPO_4 . 7H_2O$ at ordinary temperatures and this heptahydrate is also known as a mineral, phosphor-rösslerite, but it occurs only in cold wet 'muck' (10° C.) in an abandoned mine working near Schellgaden, Salzburg, Austria.¶ Perhaps phosphor-rösslerite could be formed under Antarctic conditions in winter. If so the newberyite may be its dehydration product.

PHONOLITES AND TRACHYTOID PHONOLITE

A phonolite and a phonolitic trachyte, both possibly *in situ*, were collected by Priestley on the Northern Party's first climb to the top of the Cape. These were found at 900 feet above sea-level. The same phonolite was found by G. P. Abbott on a later visit and it is interesting to note that Sir Ernest Shackleton during the Discovery Expedition of 1902 found a specimen of the same phonolite at 'the top of the Cape' [B.M. 87171, 23].

The only other representatives of rocks of these kinds, apart from pebbles on Ridley Beach, are erratics. They come from two sites: (1) a remarkable patch of 'agglomerate' exposed on the northern face of the cliff at Cape Adare; and (2) the plateau between 800 and 1,200 feet above sea-level on the top of the Cape.

The erratics from these two sites will be described below (p. 129 and p. 136).

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* Dana, E. S., The System of Mineralogy, 7th edition, 1951, vol. 2, p. 710.

† Richards, G., Amer. Min., 1928, vol. 13, pp. 347–401.

‡ Daly, R. A., Proc. Amer. Acad. Arts and Sci., 1925, vol. 60, p. 10.

§ Vertushkov, G. N., Mém. Soc. Russe Min., 1955, ser. 2, vol. 84, pp. 218–220.

|| Priestley, R. E., British (Terra Nova) Antarctic Exp. 1910–1913, Physiography, 1923, p. 3, footnote.

¶ Friedrich, O. M., and Robitsch, J., Zentr. Min., Abt. A, 1939, pp. 142–155.

It is worth noting here that white, powdery coatings similar in appearance to the newberyite, but more easily removed, were found on some loose blocks of kenyte on Mount Erebus [B.M. 1953, 86 (16)] but they proved to be thenardite, Na_2SO_4.

Phonolite

The phonolite found at 900 feet above sea-level [226–228 and 230] is a dull greenish black rock, aphanitic and compact. On its weathered surfaces it develops a mass of small rounded bodies closely packed together and this led to its being first described in the field as a variolitic basalt and under that name it is figured in Priestley's memoir on the Physiography of South Victoria Land (1923, plate 42), (Plate 1, fig. 4). Pebbles of the same phonolite were found on Ridley Beach and also some large fragments of the same rock but without the peculiar weathering. One of these [322] is deep olive-grey in colour and aphanitic, the other [351] deep slate-olive and has many small insets of feldspar in an aphanitic groundmass. The feldspar insets appear to be anorthoclase. Under the microscope it is seen that there are also occasional micro-insets of pinkish vinaceous pyroxene.

The groundmass consists of abundant laths of alkali-feldspar and small, rough-edged prisms of aegirine-augite, magnetite, small amounts of pleochroic green aegirine, and some flakes of deep brown amphibole or, possibly, cossyrite. Feldspar is the dominant light mineral but there are also abundant colourless prisms of nepheline, 0·025 mm. across, and, between the nephelines, colourless isotropic material of very low refractive index that is probably sodalite. The aegirine of the groundmass, where well developed, forms subophitic plates partially enclosing the feldspar laths. It is pleochroic from deep grape-green to deep olive-buff. The pleochroism of the amphibole is from cinnamon-brown to very dark brown, almost opaque.

Nothing has been detected in the microstructure or texture of the groundmass to account for the weathering out of the globular bodies. On broken or naturally exposed surfaces the specimens collected high up on the Cape show small polygons, 3 to 5 cm. across, faintly outlined by narrow, pale grey margins. One of the pebbles from the beach [348] shows circular areas of dull greenish black colour in a very pale olive-grey base. It is this paler weathering material which weathers out, leaving the more resistant parts standing out as rough spheres.

The specimen of this phonolite collected by Abbott at 1,000 feet [674] contains many angular fragments of aphanitic black basalt. Some of them are 3 cm. across but there are also many small subangular black patches no more than a millimetre or two across. These represent basalts through which or into which the phonolite was intruded. The angular fragments are mostly compact, aphanitic, very fine-grained olivine-basalts, and the small subangular patches show enough of their original texture to prove that they also are basalt xenoliths. It is doubtful if any of them can be identified with any of the basalts described above as *in situ* on the Cape and the best that can be said is that a representative specimen with small skeletal olivine micro-insets and abundant laths of labradorite in a dense brownish groundmass resembles the groundmass of the porphyritic olivine-basalts, Type C, from the pseudo-cave (p. 118).

Trachytoid Phonolite

A somewhat vesicular, neutral grey lava [231] was collected with the phonolites at 900 feet up on Cape Adare. The colour of this rock ranges from neutral grey to deep slate-olive. Vesicles are small, numerous, and very irregular in form. The rock is very rough to the touch and rather resembles in texture the well-known Niedermendig millstone lava. Only a few very ill-developed insets of feldspar are visible in the hand-specimen. Under the microscope it is seen that there are small micro-insets of a pale green pyroxene, alkali-feldspar, some magnetite, and some partially resorbed brown hornblende.

Prior described the same rock from a specimen in the Southern Cross collection [B.M. 87171, 31] as 'showing an approach to the hornblende-basalts' (1902, p. 329), presumably on account of its resorbed hornblendes.

The groundmass consists of abundant fibres or very slender prisms of a tea-green pyroxene, a few brown-stained flakes possibly representing amphibole, and many small magnetite cubes in a base of slender microliths of alkali-feldspar. Microchemical tests show that a feldspathoid is concealed in this colourless base but no crystal form to suggest nepheline was seen. The feldspar microliths average 0·03 mm. in length and the pyroxene micro-insets 0·1 mm. Feldspar insets are up to 1 mm. long. The pyroxene is aegirine-augite with pleochroism, α pea-green, β olive-buff, γ tea-green. The brown hornblende shows a long prismatic or bladed habit. The pleochroism is α' warm buff, γ' Dresden brown. The smaller hornblende insets are completely replaced by aggregates of small opaque grains. There are also in this rock some small segregations of brown hornblende with stout laths of plagioclase of much coarser grain than the feldspars in the rest of the rock. They are rather like the hornblendic segregations described by Prior in the trachytoid phonolite of Observation Hill at Hut Point, Ross Island (1907, p. 118 and fig. 66).

III. THE BOULDER-BEARING AGGLOMERATE ON THE NORTHERN FACE OF THE CLIFF

THE AGGLOMERATE

Priestley discovered and collected extensively from a patch of a remarkable agglomerate exposed on the northern face of the cliff at Cape Adare. He has described it in his memoir on the Physiography of the region (1923, p. 11) and photographs by Staff-Surgeon G. Murray Levick, reproduced by kind permission in this report (Plate 1, figs. 1 and 2), show its situation on the cliff and the remarkably rounded small boulders and cobbles it contains. Priestley saw, and recorded in his diary, in this agglomerate blocks of greenish greywacke and of other rocks resembling dolerite or norite, granites, schists, etc., and he collected many specimens, several of fair size, with a good deal of tuff matrix adhering to them.

The following is Priestley's own account of the finding of this agglomerate, written in his diary at the time, forty-six years ago:

'3/10/11. I walked out further than I have yet been round Cape Adare and at the farthest place I reached I bore in towards a lenticle of brown rock dipping as all the layers do about 5° towards the west and within a hundred feet of sea-level. A good deal of this had fallen recently on the ice-foot and I collected from there. The rock proved most unusually interesting for it was a basalt agglomerate, rather friable, containing numerous erratic boulders as an essential part of its composition. The most common types of rock were the green quartzite at present common (as an erratic)* on the top of the hill, granite of different types, diorite, and a (rock which reminds me strongly of a)* hypersthene norite or dolerite rich in iron. These were embedded in a loose friable cement and the majority of the pieces I obtained came away from the groundmass, but I managed to secure several bits of the main types of erratics with groundmass attached to them. The erratics were not in one plane but scattered evenly through the blocks and the jointing had taken place through many of them. The largest blocks I saw were a block of quartzite whose exposed face was approximately 12 inches by 14 inches and a block of the dolerite or norite which was well rounded and of the typical triangular shape assumed by so many of the erratics. Its exposed face was about 18 inches in greatest length by 9 inches in greatest width. . . . I also collected two or three specimens of a light yellow tuff that had fallen from some round, exposed sections in the cliff. These masses of tuff in the cliff were generally rounded and very small and might be called "pockets".

'22/10/11. Levick and I walked out beyond Cape Adare and took three photographs of and collected a couple of dozen specimens from the erratic-bearing agglomerate . . . secured several very convincing specimens of fair size of undoubted erratics, including some granite boulders with a good deal of matrix adherent to them.'

This agglomerate presents quite a problem. It apparently contains blocks which Priestley thought must be ice-borne, but its matrix is undoubtedly a volcanic tuff and all the specimens collected are of volcanic rocks but many of these are rocks related to types at present known only as erratics on the plateau at the top of the Cape. Others, as will be shown, have the characters of sanidinites and are thus quite in keeping with the interpretation of this deposit as volcanic.

The matrix adhering to the 'boulders' collected is a fine-grained pale, cinnamon-drab, sandy-textured aggregate containing many angular fragments of rock and great numbers of very small lapilli. The rock fragments are for the most part fine-grained rocks. Some of them are like trachytic and phonolitic rocks, others are fine-grained dark basaltic rocks. Under the microscope it can be seen that the matrix is itself an aggregate of small lapilli of volcanic rocks with here and there a fragment of a clastic, sedimentary rock such as could be derived from the slate-greywacke formation of the district. A considerable variety of rocks is represented among the lapilli but the majority are alkali-trachytes and trachytoid phonolites. Some are pumiceous glassy types with abundant little crystals of feldspar and brown hornblende, and many are of various kinds of fine-grained basalts, and a very few are of sedimentary rock. The base in which these lapilli are packed is extremely fine-grained and consists of broken glass with crowds of minute crystallites of colourless pyroxene, brown hornblende, and feldspar. These crystallites are extremely small and more definite identifications would be difficult. There are some fragments of larger crystals of feldspar, pyroxene, and hornblende lying among the lapilli.

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* The two phrases in parentheses are additions from the quotation printed on p. 11 of Priestley's memoir on the Physiography referred to above.

In addition to this well-consolidated cinnamon-drab tuff in which the fragments and 'boulders' are imbedded, two other kinds of volcanic tuff were collected from this agglomerate exposure.

One of these, represented by half-a-dozen specimens [652, 653, 654, 658, 660, 661], is a trachyte-tuff. It is pale buff in colour, rather friable, and consists of close-packed small buff-coloured pellets 2 to 3 mm. in diameter in a soft matrix. There are also a few small sub-angular fragments of fine-grained basalt but these are rather scarce. The buff-coloured pellets and the soft matrix are pumice, mostly comminuted, but even in the smallest fragments crowded with crystallites of feldspar. There are a few larger fragments of pumice, some of a glassy trachyte with small insets of feldspar, and some fragments of anorthoclase and of pyroxene.

The other specimen [672] is also trachyte-tuff but olive-green in colour. This consists mainly of small lapilli, 3 to 4 mm. across and ranging up to 1 cm. in diameter. Most of the lapilli are of trachyte, though there are also many of dense glassy basalt, and scattered fragments of pyroxene and plagioclase, and fragments of pumice. The very fine-grained base is a colourless glass with microliths of feldspar. It is much richer in microliths than the paler glassy trachyte tuff described above.

It is not known how these trachyte-tuffs are distributed or what their relation is to the more consolidated 'boulder'-bearing agglomerate at this exposure.

SODALITE-TRACHYTES

Many of the 'boulders' collected from the 'agglomerate', some with the matrix still adhering to them, prove to be sodalite-trachytes, grading in some specimens into trachytoid phonolites. Most of them are somewhat coarse-grained for lavas. Weathering has slightly altered many of them and the colours range from greyish olive and slate-olive in the freshest and coarser-grained specimens to drab and hair-brown in the more compact and finer-grained ones.

In thin section these rocks are seen to be porphyritic with abundant small insets and micro-insets of alkali-feldspar in a groundmass of alkali-feldspar with abundant small micro-ophitic patches of green pyroxene and opaque material, probably altered amphibole. All show in the base patches of isotropic sodalite occurring as poecilitic patches enclosing feldspar laths of the groundmass. The sodalite is colourless when fresh but it is usually slightly stained brown in the drab and hair-brown coloured specimens. Most sections of these rocks show occasional micro-insets of nepheline, partly fresh and partly isotropic and brown-stained like the sodalite. These nephelines sometimes have a partial fringe of dark green pyroxene. In some specimens nepheline seems sufficiently abundant to warrant their reference to trachytoid phonolites and one of these is mentioned below.

Another occasional constituent of these rocks is olivine as irregular rounded crystals up to 0·6 mm. across. These are slightly yellow in thin section. In some cases they are surrounded by a border of dark green pyroxene (Plate 3, fig. 5). Opaque ore is present in some sections but most of the opaque material seen is probably altered amphibole.

The feldspar of the insets is anorthoclase. Universal stage measurements showed that the plane of the optic axes is normal to (010), and a determination of the optic axial angle gave $2V = 50°$, negative (values plotted for V ranged between 24° and 30°). The insets are generally rectangular in section and are often in roughly parallel alinement. Many of them are Carlsbad twins. Some indistinct twinning and cross-hatching was observed in certain positions of the sections.

The pyroxene is mostly aegirine-augite. Measurements of extinction angles, $c:\alpha$ range from 35° to 40°. Basal sections are pleochroic, the colours ranging from pale olive-buff to deep olive-buff and chamois for vibrations corresponding to γ'; and for vibrations in the α' and β' directions, shamrock-green and light grape-green to deep greenish glaucous.

Some aegirine is also present among the groundmass pyroxenes. In one specimen [663] prismatic sections gave $c:\alpha = 6°$, and pleochroism α' near grape-green, γ' apricot-yellow.

There are several variations from this average type in addition to the colour variations already noted. One of these [656] has abundant micro-insets of a pale green aegirine-augite. Hand-specimens of this variety are greenish grey (storm-grey) in colour, rather coarse-grained for trachyte, and, like the others described above, they show a sheen from feldspar cleavages on fractured surfaces.

A more fine-grained and more compact example of the same variety is slate-olive in colour [697]. Aegirine-augite micro-insets in this rock are similar to those described above but $c:\alpha = 43·5°$. A frequent accessory constituent in this rock is opaque 'ore', often with hexagonal outlines, probably magnetite. The groundmass consists of abundant laths of alkali-feldspar in partly parallel alinement, with small patches of pale green aegirine and pale brownish-fawn amphibole, both abundant. There are some areas in which the feldspars lie in patches of low refracting material of very low birefringence, probably a zeolite.*

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* A specimen [703] otherwise resembling 656 and 697, shows in the hand-specimen rounded areas, 1 to 2 mm. across, slate-olive in colour, in a cream-coloured base. This colour distribution is related to alteration affecting the base of the groundmass of the rock. The thin sections show that the dark rounded areas are slightly turbid and dusty. The groundmass feldspars lie in an apparently isotropic base of low refractive index. In the turbid areas this base has vast numbers of very small (less than 2μ), round, colourless inclusions, apparently of low refractive index. The nature of these bodies is not yet known. Similar round dark 'varioles' are seen in 667 but they do not seem to show up in the thin section in the same way.

Another variation [689] is a paler-coloured 'trachyte', vetiver-green to greyish olive in colour, in which the groundmass laths of feldspar tend to be grouped in radiating sheaves. With the feldspar are associated very abundant grains of pyroxene and altered brown amphibole and many tiny grains of opaque 'ore', and some isotropic and some altered, birefringent base. Occasional small insets of brown hornblende with $c{:}\alpha = 11°$ show pleochroism α' deep grape-green, γ' cinnamon-buff.

One other variation, a sodalite-trachyte with a remarkably high proportion of dark minerals, is a compact aphanitic rock, deep brownish-drab in colour [705b]. This contains only a few small (2·5 mm.) insets of alkali-feldspar and occasional olivine crystals up to 0·5 mm. across. The main constituent is alkali-feldspar which forms very slender laths, close packed and in parallel alinement. Throughout the feldspar and enclosed by them are vast numbers of minute sodalite crystals, some showing hexagonal shapes and up to 0·014 mm. across but mostly less. The dark minerals are aegirine and altered cossyrite crystals. They form perhaps 20% of the rock, and are partly responsible for the dark colour of this specimen, but in addition a colloidal brown mineral (ochraceous tawny) forms films on feldspars and coats fractures and cleavage surfaces. Other fragments similar in appearance to this rock are frequent in specimens of the enclosing agglomerate.

Trachytoid Phonolite

A variation of these sodalite-trachytes that is probably best described as a trachytoid phonolite [664] is a compact, dark greyish olive rock with many small indistinct insets of alkali-feldspar in an aphanitic crystalline groundmass. The insets are anorthoclase; they are rectangular in section and show Carlsbad twins with occasionally traces of indistinct cross-hatching. There are many micro-insets of the same kind of feldspar, so that the fabric is seriate porphyritic. There are a few small insets also of green aegirine-augite similar to that described above. The pleochroism is α' dark greenish glaucous, β near grape-green and γ' cream-buff. 2V is near 70°, negative. Magnetite(?) with hexagonal sections (cubo-octahedra) is a frequent accessory.

The groundmass is very fine-grained and consists of a greyish green turbid pyroxene(?) and deep brown amphibole or cossyrite in very small micro-ophitic patches or free as small crystals. These lie all through the groundmass of slender laths of alkali-feldspar set in a faintly brown-stained low-index base that is partly isotropic. This base is probably nepheline rather than sodalite and it is on that assumption that the rock is classified as phonolite and described separately from the sodalite-trachytes.

Alkali-trachytes

Some of the boulders in the agglomerate lacking the sodalite that is so constant in the sodalite-trachytes described above are best separately listed under alkali-trachytes.

These [657, 702] are deep olive-grey to dawn-grey in colour and fine-grained and compact with insets of feldspar 2 to 3 mm. long.

Thin sections show the feldspars to be simple Carlsbad twins of anorthoclase with traces of vague twinning. They are abundant and there are also frequent micro-insets of aegirine-augite. The pyroxene is rather similar to those described above with weak pleochroism; deep dull yellow-green, reed-yellow to olive-yellow. Another frequent constituent is olivine as small, pale yellowish, irregular crystals and small magnetites(?) are also common. The groundmass consists mainly of short crystals of alkali-feldspar, slightly elongate but with irregular edges and not showing parallel alinement. With these are small fragments of pale green pyroxene and dark brown amphibole or cossyrite?, both frequent. The pyroxene and amphibole are in micro-ophitic relation to the feldspar. The groundmass feldspars are single crystals or Carlsbad twins, and, in many sections, they give straight extinction parallel to 010.

Sanidinites

The rock fragments in the agglomerate that were referred to above as sanidinites are leucocratic, rather friable rocks with grain-size about 5 mm., but a few are fine-grained, 1 to 2 mm., and speckled, pepper-and-salt rocks quite resembling fine-grained diorites in appearance.

The best example of these rocks [686] is a small boulder, 5 × 7 × 10 cm., pale cream-coloured, and rather friable and granular in texture. It consists mainly of feldspar speckled with black crystals and flakes, among which a black mica is conspicuous and occasionally forms flakes 8 mm. across. The feldspars, which are fresh and have a glassy lustre, are sometimes as much as 10 mm. long by 2 mm. wide, and crystals 4·5 mm. in length are frequent, but the average grain-size is about 2 to 3 mm. In this specimen all the feldspar proves to be anorthoclase. The crystals are allotriomorphic and have one cleavage (001), very well developed in thin sections. Some of the crystals show rather patchy extinction and a few show vague, very thin, twin lamellae.

A pure sample of this feldspar was prepared by Mr. P. M. Game and was analysed by Mr. D. I. Bothwell with the result given in column 1 of the table below. Inspection of the sample under a binocular microscope showed the only impurity to be a few flakes of biotite and the proportion of these present was very small indeed.

The analysis shows that there is a small deficiency in both SiO_2 and Al_2O_3 below the percentages required to satisfy both alkalies and lime for feldspar but the effect of this on the calculated ratio of feldspar molecules is very small. Allotting all the CaO to anorthite and deducting sufficient of the orthoclase molecule to satisfy MgO and FeO (Fe_2O_3) for biotite, the composition may be fairly stated as Or : Ab : An = 36 : 62·6 : 1·4. The specific gravity, determined by Mr. Bothwell, is 2·57 ± 0·01.

Measurements on the universal stage gave values for V from 25 to $26\frac{1}{2}°$, negative, and refractive indices for sodium light were determined by the Becke line method as, α' 1·5259, γ' 1·5318, ± 0·0005.

Comparing these values with those given by O. F. Tuttle (1952, pp. 557 and 559) for 2V and for refractive indices of the alkali-feldspars both 2V and α' and γ' are high for a feldspar of the composition $Or_{36}Ab+An_{64}$. They are, however, sufficiently near to Tuttle's values to show that the feldspar analysed falls in his 'sanidine-anorthoclase cryptoperthite' series. Among the feldspars measured by Tuttle the one nearest in composition to the feldspar now described is anorthoclase from the Azores. Its composition and the values for 2V and refractive indices are given in column 2 of the table.

TABLE II

	1	2
SiO_2	66·8	66·97
TiO_2	nil	0·04
Al_2O_3	19·1	18·75
Fe_2O_3	0·2	0·88
FeO		
MnO	nil	—
MgO	0·2	0·00
CaO	0·3	0·36
Na_2O	7·7	7·88
K_2O	6·4	5·39
P_2O_5	tr.	—
H_2O+	nil	0·01
H_2O-	nil	0·03
Total	100·7	100·31
Or	36	32
Ab	62·6	66
An	1·4	2
2V	(50°)	46°
α'	1·5259	α1·5239
		β1·5299
γ'	1·5318	γ1·5308

1. Anorthoclase from sanidinite, Cape Adare. Anal. D. I. Bothwell.
2. Anorthoclase from 'Grande Caldeira' [Caldeira das Sete Cidades, Saõ Miguel], Azores. Anal. J. H. Scoon. (O. F. Tuttle, Amer. Journ. Sci., 1952, Bowen Volume, p. 555.)

It seems certain that the feldspar in the sanidinite [686] is all of one kind and that it is correctly assigned to anorthoclase. (Plate 3, fig. 3.)

In some of the other specimens of the sanidinites from this deposit there appear to be two kinds of feldspar in that some of the feldspar crystals show fine albite-twinning more definite than the rather patchy and obscure lamellar twinning shown by some anorthoclase. Also in these rocks determinations of refractive indices by the immersion method indicate that the feldspar showing fine twin-lamellae has a higher refractive index than the untwinned feldspars in the same rock.

Values obtained for the refractive indices for sodium light were:

Untwinned feldspar: α' 1·523₅; γ' 1·529–1·530.
Twinned feldspar: α' 1·528–1·534; γ' 1·536–1·538.

The extinction angle measured from the trace of the twin lamellae is 5°.

The values obtained for the twinned feldspar are still within the range for anorthoclase, though they could also fit for a plagioclase with An up to, say, 8 per cent.

The dark minerals are brown amphibole, green pyroxene, biotite, and some opaque 'ore'.

The amphibole has intense absorption parallel to β and in basal sections pleochroism is tawny olive to black. The absorption for vibrations along the length of longitudinal sections is also very strong, and it was not possible to determine certainly the angle of extinction or the sign of elongation. One section gave an extinction angle of 33°. These characters, so far as they go, agree with those of aenigmatite or cossyrite.

The pyroxene, in 686, is aegirine-augite, similar to that in the sodalite-trachytes described above. Pleochroism is: α' deep bluish glaucous, β' deep olive-buff, γ' tea-green. $c{:}\alpha = 31°$. Some of the pyroxenes have darker outer shells, and there are some crystals all aegirine with $c{:}\alpha = 12°$, and in one specimen [653] $c{:}\alpha = 9°$, and pleochroism is α' very dark green, γ' deep colonial buff.

The biotite is intensely pleochroic from ochraceous buff and Dresden brown to black.

The three dark minerals are closely associated and they may form a reaction series. Some sections show amphibole surrounding pyroxene and in places both partially surround the biotite, but the reverse relation can also be seen.

In some cases the ferromagnesian minerals have undergone resorption. Thus, in 659, relics of brown amphibole lie in a dense swarm of rods and tiny cubes of magnetite (?), a few flakes of biotite, and prisms of aegirine.

Accessory minerals identified are apatite and, in some specimens, sphene. The latter is abundant in a dark variant of the sanidinites described below. Calcite occurs filling interstices in one specimen [686] and the same specimen contains colourless interstitial patches that may represent altered cancrinite (see below, footnote p. 133).

The texture of these sanidinites varies somewhat. In some [686] it is allotriomorphic as described above, but in others [653, 659] it is hypidiomorphic with the feldspars tending to form laths and thin plates 4 or 5 mm. long. In some specimens between the larger feldspars there are areas where the feldspar is fine-grained and granular, and others where it is fine-grained but occurring as laths and divergent radial. In such areas dark minerals are more frequent and the biotite is pale brown and shows much less intense absorption than in the coarser-grained, more normal, parts of the sanidinites. Thus its pleochroism in 659 is ochraceous orange to light buff or pale ochraceous buff. One sees in some of these fine-grained areas an approach to the mineral composition of some of the alkali-trachytes and the resemblance is enhanced by the presence of some interstitial patches of a colourless, weakly birefringent mineral, perhaps a zeolite.

A darker variety [671b], rather finer grained than the more leucocratic examples, owes its darker colour to very evenly distributed ferromagnesian minerals which are present in considerable abundance. There are a few larger feldspars, 5 to 8 mm. across, but apart from these the rock is very even-grained, 1 to 2 mm. The texture is allotriomorphic granular, though the feldspars tend towards a tabular habit. The feldspars are Carlsbad twins and some show vague albite-twinning. They are almost certainly anorthoclase.

The ferromagnesian minerals are a brown amphibole, a pyroxene, and biotite.

For the amphibole $c:\gamma = 11°$, and the pleochroism is α' cinnamon-buff, β' olive, and γ' buffy olive.

The pyroxene is aegirine-augite. $c:\alpha = 30°$. Pleochroism: α' deep malachite-green, β' malachite-green, and γ' pale olive-yellow to reed-yellow.

The biotite is intensely pleochroic from ochraceous buff to clove-brown, almost opaque.

All these ferromagnesian minerals are well crystallized and they tend to be closely associated and clustered together. Sphene is also present in these groups as well as some apatite which, in this specimen, is also present as an accessory mineral throughout.

Cancrinite-bearing Sanidinite

One of the sanidinites differs from all the others in containing cancrinite. It is a small fragment only about 3 cm. across and is the only one of its kind found in the collection. This is unfortunate, as the feldspars present an interesting problem.

The specimen consists mainly of feldspar, rectangular and tabular in habit, up to 8 mm. long and 2 mm. across. The dark mineral is biotite forming glistening black flakes and under the microscope showing intense pleochroism, buckthorn-brown to opaque. Neither amphibole nor pyroxene was observed. Sphene is quite frequent and there is some interstitial calcite. The cancrinite, colourless in thin section, occupies roughly triangular interstitial areas between the feldspars. For the most part it is fresh and shows its characteristic high birefringence, low refractive index, and negative elongation.*

The feldspar in this rock is of considerable interest. Many of the feldspars show an approach to rectangular forms. Many broad plates show no twinning, others more rectangular in outline show albite lamellae; all the sections show mottling due to the association of the two kinds. The twinned feldspar is mottled by intergrown untwinned feldspar of lower index. In the platy sections that show no twinning the birefringence as well as the refractive index is higher in the host.

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* In the typical sanidinite described above [686] there are some interstitial areas filled with a granular aggregate of colourless minerals that may possibly represent altered cancrinite. The minerals have not been identified. They comprise: rounded grains of an isotropic mineral of low refractive index; groups of radiating blades and fibres of another apparently isotropic mineral with refractive index less than balsam; and a third, rather turbid and highly birefringent, that may be calcite. In the same specimen calcite is seen occasionally filling interstices.

Measurements on the Universal stage show that the untwinned feldspar that forms patches and cores in the clearer, more highly refractive feldspar has the optical orientation of sanidine and is almost uniaxial. Measurements by Mr. P. M. Game on some half-dozen selected crystals gave the following data: $\alpha \wedge 010$: $\alpha \wedge$ the a-axis $[100]=9°$; $001 \wedge 010=89°$; $[001] \wedge \perp(001)=26°$: $2V=$ approximately $0°$.

The approximation to zero of 2V was checked many times on crystals of differing orientation.

The refractive indices for the untwinned feldspar in this rock for sodium light are: α' 1·5199, β' 1·5239 ± 0·0005. These are not far from values given by E. Spencer for sanidine from the Eifel, for which, however, $2V=24°$ (Spencer, 1937, p. 458 and pl. 18) or 17° (Tuttle, 1952, p. 555). The composition of the Eifel sanidine is $Or_{78}Ab_{21}An_1$.

The twinned feldspar in the section has proved very difficult to identify. All the sections approximately perpendicular to (010) show fine twin-lamellae parallel to that plane, but in the great majority of sections the lamellae are too fine to permit of measurements. However, fairly good readings were obtained on four more coarsely twinned crystals. The mean value for the orientation given by these four are: $\alpha \wedge [100]=15°$, $\gamma \wedge \perp(010)=15°$, and $2V_{\alpha}=85{\cdot}6°$ (on one direct measurement). Refractive index measurements gave for twinned cleavages: α' 1·5296, γ' 1·5363 for sodium light. These values and the optical data (except the negative sign of the optic axial angle) agree tolerably well with albite near An_4 referred to the optical orientation based on universal stage measurements and with albite near An_8 judged by the refractive indices.

As there is so little material available one cannot proceed with more detailed investigation of these interesting feldspars. The data obtained seem to indicate that the mixed feldspar is an antiperthite consisting of near uniaxial sanidine in an albite host.

In this connection it is interesting to note that P. Quensel (1914, p. 166), describing the alkaline rocks of Almunge in Sweden, records two kinds of feldspar associated with the cancrinite, nepheline and albite in the canadites. These are soda-orthoclase (in the sense of Brögger, i.e. showing no twinning), and microcline-microperthite (antiperthite) in which patches of microcline are distributed in large albite crystals. This microcline-microperthite (antiperthite) is however scarce in typical canadites.

In another well-known cancrinite-bearing nepheline-syenite, litchfieldite, antiperthite with patches of microcline in large albite crystals is described by W. S. Bayley in his description of this rock (1892, p. 237).

If the original feldspar in this cancrinite-bearing sanidinite was originally a patchy antiperthite the present nearly uniaxial sanidine may be the result of subsequent heating of the 'bomb' in the deep-seated part of the Cape Adare volcano.

Published records of uniaxial natural sanidines are very rare. A. Mulheims (1888, p. 235) reported sanidine from Wehr in the Eifel as uniaxial but this was on the basis only of refractive index measurements for which he found β and γ to be equal. He is quoted by O. Mügge (1925, p. 666) as authority for $2E=0°$ for this sanidine. Mügge also quotes Des Cloiseaux (1862) as having found $2E=17°$ for red light for 'orthose' (sanidine), also from Wehr. More recently O. F. Tuttle (1952, p. 5) quotes F. Tucan for $2V = 15–18°$ for a feldspar in dacite from Yugoslavia with composition $Or_{52}Ab_{43}An_5$.

The identification of these medium-grained feldspathic rocks in the agglomerate as sanidinite is well supported by their close similarity to described sanidinite bombs from other volcanic areas. In this connection the sanidinites of Saõ Miguel in the Azores have already been mentioned. These were described in some detail by A. Osann (1888, p. 117) and more recently by P. Esenwein (1929, p. 125), who gave a new analysis, and determined 2V for the feldspar as 60°, negative, and extinction $a{:}\alpha = 13°$ (op. cit. p. 111).

In the Laacher See district in Germany the name sanidinite has been used in a wide sense to include a great variety of ejected blocks in the tuff, but there are also great numbers of sanidinites consisting mainly of feldspar, and it is interesting to note that cancrinite has been described from some of these by R. Brauns and J. Uhlig (1913). It had been described earlier as scapolite. The canrinite-bearing bombs are regarded as original syenitic material (1913, p. 210).

The sanidinites have no known near analogues among South Victoria Land rocks at present described. They do not closely resemble the sanidinites in the Mount Cis 'trachyte' described by J. Allan Thomson (1916, p. 131), which are rich in pyroxene and in olivine and carry neither amphibole nor biotite.

An erratic from Cape Royds described by W. G. Woolnough (1916, p. 172) as sodalite-syenite (1916, p. 172, No. 535) has a similar mineral assemblage to the sodalite-trachytes of Cape Adare but no occurrence of such a rock *in situ* in the Ross Archipelago or on the mainland is known.

IV. THE ERRATICS FROM THE PLATEAU ON THE TOP OF CAPE ADARE

Priestley has given some account of the plateau and of the strew of erratics on its surface in his memoir on the Physiography (1923, p. 10), and a note on the erratics of plutonic rocks on the plateau and some remarks on their possible sources was published in a report on the plutonic and hypabyssal rocks of South Victoria Land in 1924 (W. Campbell Smith, 1924, p. 214).

Compared with the plutonic and sedimentary erratics the volcanic rocks collected are few. Two of the specimens [579 and 584] are the same as the trachytoid phonolite from 900 feet above sea-level described above. Five of them are basalts of which two may not be far from their outcrops. The remainder, 8 in number, are trachytoid phonolites and alkali-trachytes not known to be *in situ* on the Cape but related to some of the types described from the 'agglomerate' on the northern face of the cliff. Briefly described, these are as follows:

Trachytoid Phonolites and Alkali-trachytes

585. A small boulder, smoothed on three faces. Aphanitic, slate-olive in colour. compact. In thin section it is seen to contain small insets of thin, tabular feldspars and a few micro-insets of a tea-green pyroxene and occasional micro-insets of magnetite. The groundmass consists of closely packed laths of alkali-feldspar with abundant small 'mossy' patches of dark green aegirine and a brown amphibole or cossyrite. Between the feldspars are abundant small interstitial patches and hexagonal sections probably of sodalite. All the feldspars, both insets and groundmass, are affected by some alteration which renders them slightly turbid. The feldspar insets show no cross-hatching and give very low extinction angles measured from the trace of 010. They are simple Carlsbad twins.

575, 582, 588, 602. A group of four specimens all of the same kind and all broken from larger specimens seen as erratics.

These are characterized by very abundant large insets of anorthoclase showing the characteristic cross-hatching and some having lozenge-shaped sections common for this feldspar. There are occasional micro-insets of a pale purple drab, green-shelled aegirine-augite, and frequent pseudomorphs of hornblende now represented by dense aggregates of magnetite and a green pyroxene. The groundmass, not very fine-grained, consists of a mass of platy and lath-shaped alkali-feldspars with pale green aegirine-augite, some altered brown hornblende and magnetite and a little sodalite. The sodalite in these rocks is not interstitial as in the sodalite-trachytes described above but occurs as thin scales actually in the feldspars. In addition to the micro-insets mentioned above there are occasional small insets of pale yellow olivine, usually rimmed by clusters of green pyroxene crystals (Compare 370 from Ridley Beach, Plate 3, fig. 2).

Examples of these porphyritic types were collected also from the beach as pebbles and a pebble of the same kind [B.M. 87171, 25] was collected by H. T. Ferrar on the Discovery Expedition and briefly described by Prior (1907, p. 116). It was one of two specimens from Cape Adare that Prior suggested bore close relations with the kenytes, but he was then using 'kenyte' in a very wide sense, and actually the relationship of these rocks to the kenyte of Mount Erebus is not a close one.

Their nearest match among described volcanic rocks from South Victoria Land is to be found in some porphyritic rocks [B.M. 87171, 622] collected by H. T. Ferrar on the Discovery Expedition from debris heaps on Minna Bluff, south of Ross Island. A somewhat similar rock was recorded by Jensen from Cape Bird (1916, p. 119) [P341].

Ferrar's specimen 622 was described by G. T. Prior (1907, p. 119) and it has been further described in the earlier part of this report on the volcanic rocks of the Ross Archipelago (1954, p. 35). In thin section it is seen to differ in some respects from the rocks described above. Hornblende insets are absent, and the feldspar insets are uniformly rectangular in habit in the Minna Bluff rock.

There are two other porphyritic rocks among the erratics which are closely related to those just described. These are:

236. This has a few small insets of plagioclase as well as the abundant anorthoclase some of which are 5 mm. in length. Also frequent are small insets of a zoned pale purple-drab and pale green pyroxene and many insets of a dark pleochroic yellowish olive amphibole, partly resorbed. The groundmass is very fine-grained and consists of abundant pale green pleochroic pyroxene and some laths of feldspar with much colourless apparently isotropic interstitial material and small patches of highly birefringent fibres, like sericite, that may represent altered nepheline.

567. The last of these porphyritic erratics to be mentioned is of rather particular interest, as it is similar to a specimen collected on the Southern Cross Expedition [B.M. 85752, 24] described and figured by Prior and claimed by him to approach 'closely to the rocks from Mount Kenya to which Professor Gregory has given the name "kenyte" ' (1902, p. 329 and plate 53, fig. 4).

It is a clove-brown to dark olive porphyritic rock with an aphanitic groundmass containing many insets of anorthoclase up to 5 mm. in length, small insets of aegirine-augite and of serpentinized olivine, and small magnetite crystals in a fine-grained groundmass of alkali-feldspar laths, grains of nearly colourless pyroxene and of magnetite, with small amounts of colourless weakly birefringent base. It does not show any insets of nepheline, as the kenytes of Mount Kenya do, and its feldspars, both in size and habit, are quite unlike those in the Mount Erebus kenytes.

An analysis of this rock was published in the report on the collection of the Southern Cross Expedition by Prior (1902, p. 329) and this has been republished in H. S. Washington's tables of analyses of igneous rocks (1917, p. 339, no. 36) and named 'phonolite'. However, its norm shows 11·64 of normative quartz. A microchemical test for feldspathoids on the groundmass was negative, so it seems probable that this rock is wrongly classified as a phonolite. If it were found *in situ* it could be further investigated.

1246. This differs considerably from the trachytoid phonolites and porphyritic types just described but is doubtless related to them. It is an alkali-trachyte with small tabular insets of alkali-feldspar, probably anorthoclase, in a groundmass of feldspar laths with much colourless, birefringent, and turbid low-index interstitial material and scattered small crystals of opaque 'ore'. Brown-stained patches may result from altered pyroxenes or amphiboles but the rock is too much altered to make further study worth while. In addition to the feldspar insets there are rare micro-insets of a pale green pyroxene. This is not represented by other specimens from the plateau but many pebbles of this trachyte were collected on Ridley Beach (see below).

BASALTS

There are only five basalts among the erratics collected on the plateau at the top of the Cape and they fall into two kinds.

One [592] resembles the black aphanitic basalt common among the pebbles on the beach. It carries neither insets nor micro-insets and consists of abundant long plagioclase laths arranged in parallel alinement in a dense and apparently partly glassy base.

This base consists of tiny microliths of feldspar, granules of augite, some translucent orange-brown pseudomorphs of olivine(?), 'dusty' magnetite and some isotropic material, nearly colourless but slightly turbid with minute inclusions.

The other basalt, represented by 591, is a porphyritic olivine-basalt that must be closely related to the porphyritic olivine-basalt, Type C, of the rocks *in situ*, but the erratic has a holocrystalline and relatively lighter-coloured groundmass. A basalt of this kind [232] with a dark, partly glassy base was actually collected at 900 feet up on the Cape at the same time as the 'variolitic' phonolite (p. 124). It has been assumed that these specimens were *in situ*. If so the erratic [592] may not be far from its outcrop.

The insets in this basalt are olivine, colourless in thin section, and more abundant insets, and micro-insets, of augite sometimes enclosing small crystals of magnetite. In the groundmass there are abundant small crystals and granules of augite and many small crystals of magnetite, laths of plagioclase, and a colourless, apparently isotropic base (Plate 2, fig. 6).

A fine example of this kind of basalt, similar to 232, is 1231, but it is not certain whether this was from the plateau or the beach. Another, 1243, about which there is the same uncertainty of provenance, is also porphyritic with olivine insets but there are fewer insets than in the other specimens of this type and the texture of the groundmass is nearer that of a trachybasalt, of which there are examples among the pebbles described below.

V. PEBBLES FROM RIDLEY BEACH

Among the pebbles collected from Ridley Beach as representing types not seen *in situ* on the Cape are several kinds of phonolitic trachytes or trachytoid phonolites and of basaltic rock. Those of trachytoid phonolites and trachytes are similar or very closely related to some of the erratics collected on the plateau and these call for no further description. Among the basalts, however, are some that show differences from any of the erratics or *in situ* rocks and it seems worth while to record these briefly.

Black, aphanitic basalts, usually with many very small vesicles, are a common type [331, 343, 430, and 452]. Pebbles of this kind are found to be feldspar-rich and poor in olivine, and they all carry xenocrysts of partly or wholly resorbed brown hornblende. Under the microscope they show very abundant small slender laths of plagioclase with a tendency to parallel alinement in a dense base of dark brown glass with minute pyroxene grains and abundant 'dusty' magnetite. There are a few small insets and frequent micro-insets of augite, plagioclase, and colourless olivine, and micro-insets of magnetite and scattered xenocrysts of the resorbed brown hornblende. Apatite as stout prisms is a rather frequent accessory.

In one pebble that belongs to this type the groundmass is not glassy but consists of very abundant laths of plagioclase with some parallel alinement, granular pyroxene, and magnetite. Small patches of calcite presumably represent an altered groundmass constituent and a few small vesicles carry zeolites(?). The plagioclase of the microliths is labradorite.

Basalts similar to these, characterized by xenocrysts of brown hornblende, were described as 'basaltic andesite' by Edgeworth David and others (1896, p. 475 and plate 14, fig. 3) and by Prior from Cape Adare [B.M. 85752, 23] and Prior also described a similar basalt from the foot of Mount Terror. From the earlier collections specimens of similar basalts are also described from Possession Islands and from Coulman Island.

Fragments of the same kind of basalt are the main constituent in a pebble of agglomerate from the beach, so it is likely that they represent an early phase of the vulcanicity rather than very recent flows as Prior seems to suggest in the Southern Cross report.

There are other variants of these aphanitic hornblende-bearing basalts and some of these may be briefly mentioned, for example:

432. A basalt with frequent small insets of plagioclase and a few of augite and xenocrysts of hornblende in a fine-grained groundmass in which brown-stained grains probably represent olivine.

368. A basalt slightly coarser-grained than the others with fresh brown hornblende insets and much augite in the groundmass, which also contains small altered olivines, magnetite, and laths of plagioclase in a colourless base that may be alkali-feldspar or nepheline. Large apatite prisms are frequent. Amygdale-like bodies in these rocks are partly filled with calcite and partly with zeolite material.

372. Another aphanitic black basalt with rare glassy insets of augite is perhaps near to the trachybasalts. This carries many small insets of a plagioclase with refractive index only slightly above Canada balsam, occasional insets of augite, and some micro-insets of augite, iddingsite after olivine, and magnetite, and occasional relics of resorbed hornblende. The groundmass consists of abundant slender laths of plagioclase with tiny magnetite cubes, granular augite, brown altered olivine(?), and small amounts of a colourless birefringent base. Purplish inclusion-rich apatite is a notable accessory. This, like several others of the basalt pebbles, is traversed by pale buff-coloured veins which contain some phosphatic material. Borchgrevink collected a similar specimen [B.M. 85752, 29].

Two other pebbles are either trachybasalts or tephrites. One of these [433] with a few tabular insets of plagioclase and some of hornblende in a rather light-coloured, slate-grey groundmass is a very good example of the veining mentioned above. The central part of these veins in this rock is colourless and partly of quite low birefringence but the yellower parts of the vein and the margin of basalt permeated by the vein material show crystals that appear to be epidote. The feldspar in the groundmass of this rock has generally rather low extinction angles and the feldspar of the insets appears to be andesine.

Two others [333 and 360] which microchemical tests show have feldspathoids in their groundmass are fine-grained neutral grey rocks with small insets of augite and micro-insets of magnetite. One of them carries also small brown hornblendes and rather large apatite prisms are frequent in both. The plagioclase has low extinction angles in both these rocks.

VI. FRAGMENTS FROM THE MORAINES OF THE NEWNES AND MURRAY GLACIERS

The Newnes Glacier

On several occasions Priestley collected from the moraines of the Sir George Newnes Glacier at the end of Robertson Bay. Many of the specimens collected are of basalts and some are tuffs.

The basalts are all variants of olivine-basalts. They are probably closely related in composition to the basalts of Cape Adare but those examined do not match any of the types of olivine-basalt found *in situ* on the Cape, nor any of the basalts described from pebbles on Ridley Beach.

The basalts collected on the moraine can be grouped under slightly different headings according to their macroscopic appearance and their mineral composition but they probably do not differ much in composition and the whole collection may have come from rocks outcropping over a very limited area.

(*a*) The coarsest-grained and most easily recognizable variety among these moraine specimens is one that should perhaps be described as a dolerite on account of the grain-size of its groundmass constituents. Specimens of this group are characterized by very abundant small dark insets in a pale olive-grey groundmass. The insets look like fragments rather than definite crystals and the rock in consequence looks more like a tuff than a lava. The dark insets, 2 to 4 mm. across, consist of black to very dark green augite and smaller olivines. The augites occasionally show rectangular outlines but most of them are irregular in outline and the small olivines are rounded. In addition there are frequent insets of glassy feldspar up to 6 mm. across.

Thin sections show the abundant insets of olivine, augite, and labradorite. Extinction angles indicate a range in different specimens from An_{60} to An_{68}. Some of the augite insets and the olivines contain many inclusions of groundmass and none of the insets are very sharply bounded. This may indicate that aggregation of insets and crystallization of groundmass overlapped considerably. Needles of apatite are frequent in the feldspars. Magnetite occurs both as small crystals in the groundmass and as micro-insets and micro-ophitic plates. The groundmass itself consists of laths of labradorite, An_{55-62}, with magnetite, small nearly colourless augites, small olivines, and small amounts of alkali-feldspar interstitial to the feldspar laths. Biotite, as small flakes, is an accessory groundmass mineral. Pyroxene in the groundmass gave $c{:}\gamma = 46°$.

(*b*) Probably closely similar to the porphyritic, doleritic type just described are specimens characterized by few insets of glassy feldspar and abundant small dark greenish brown and yellowish green olivines and fewer, darker augites in a holocrystalline light olive-grey groundmass. Some vary a little in general colour to deep olive-grey and mouse-grey and a somewhat altered specimen [GN 1026] is brownish drab.

In thin section an outstanding character of these rocks is their amazing freshness and cleanness. The insets are colourless olivine, and olive-buff augite, and plagioclase. All three are rather abundant. The feldspars are labradorite, An_{60-65}, and the augites give extinction angle $c{:}\gamma$ up to 42°.

The groundmass consists of clear laths of labradorite, An_{57-65}, and many grains of pale yellow-bordered olivine with small olivines, augites, and magnetites between the feldspar laths. A few small flakes of biotite occasionally appear in the groundmass [GN 976]. Some sections show interstitial plates of simply twinned feldspar (oligoclase?).

An altered, brownish drab specimen [GN 1026] shows black-rimmed olivines and a general darkening (reddening) of the ferromagnesian minerals and of the magnetite in the groundmass.

Specimens of a slightly coarser-grained, aphyric, and slightly drusy rock [GN 945, 977] are doleritic variants of this type. They consist of pale yellowish olivine and stout laths of labradorite, augite, and magnetite, and biotite is a conspicuous constituent. In the drusy cavities are many tiny crystals of augite or olivine, magnetite, and feldspar.

(*c*) The third group of porphyritic basalts from the moraine are all very dark, olivaceous black to dark olive-grey, and carry a few insets of glassy feldspar and some, less noticeable, of olivine and augite. The feldspars are labradorite near An_{65}, and are short tabular in habit. The groundmass is very fine-grained aphanitic. Several of the specimens are vesicular. Some slightly altered specimens are brownish drab in colour.

The dense groundmass of these specimens is difficult to resolve. In a representative specimen [GN 1049] it is seen to contain abundant small laths of labradorite (An_{60-65}), yellow 'stained' olivine, minute prisms of colourless augite, and grains and cubes of magnetite. There is a small amount of interstitial base which, in one case [GN 1035], is colourless feldspathoid, but in other specimens [e.g. 1021] it is dark brown glass with inclusions of thin blades of opaque 'ore' and some acicular crystallites.

The altered brownish drab coloured examples of this group show in thin section an increasing opacity in the ferromagnesian constituents of the groundmass and the olivine insets have strong black borders and are completely filled with minute black inclusions which lie in a colourless birefringent base. In hand-specimen the olivines are quite black and opaque. This sort of alteration has been observed also in basalts from Cape Adare itself and was earlier described by Edgeworth David and others (see p. 119).

One specimen of this group contains a xenolith of a medium-grained sandstone recalling the xenoliths so frequent in the Cape Adare basalts.

In addition to the porphyritic basalts there are several variations of aphyric fine-grained olivine-basalts.

(*d*) Most widely represented is a basalt with few visible small olivine insets in an aphanitic neutral grey to dark neutral grey groundmass. Several of these basalts have very irregular flattened vesicles coloured on weathered surfaces citrine-drab and carrying numerous lustrous black semi-globules or botryoids of pitchy-black mineral (limonite) and some minute white crystals (perhaps feldspars weathering out) and glistening tiny crystals of magnetite, and some hematite. Several other rocks in this group are slightly porous in structure and these also show the bright metallic crystals in the cavities, while over the whole rock feldspar cleavages are clearly visible, indicating a holocrystalline and medium-grained texture. Several specimens of this group are slightly reddened and are brownish-drab in colour and these, in common with others altered in this way, show in thin section olivine micro-insets black rimmed and nearly opaque with inclusions of 'ore'.

A great many of the specimens of this type show the slight reddening in colour and in all these the olivines are altered and almost filled with the minute black inclusions and the ferromagnesian minerals are opaque. A fresher example of the group [GN 938] shows micro-insets of pale yellowish olivine and very abundant plagioclase present both as micro-insets and as small laths as well as in the groundmass. Extinction angles in the micro-insets indicate basic labradorite near to bytownite, but the groundmass microliths are less basic labradorite, in one specimen [GN 932] near An_{50}. The very fine-grained groundmass consists of the plagioclase microliths with much granular augite, probably olivine, and much magnetite as very small grains. Some sections [GN 932] show small amounts of interstitial alkali-feldspar.

One specimen of this kind [GN 934] is much altered, the augite appearing yellow like epidote and the olivine red-brown in the thin section. It may have been a xenolith from a later lava.

(*e*) Represented by only two specimens [GN 943, 1002] is a dense, aphanitic olivaceous black to iron-grey olivine-basalt that carries small amounts of accessory biotite. It has small insets and micro-insets of nearly colourless olivines with brown borders, and many flakes of brown biotite and abundant small micro-insets of plagioclase in a very fine-grained groundmass. The plagioclase of the micro-insets is basic labradorite, An_{65-70}.

The biotite has pleochroism, ochraceous orange to colourless, and resembles in colour the biotite in some nepheline-basalts. The groundmass consists of microliths of labradorite (near An_{63}) with granular augite and magnetite between the feldspars. One section showed small amounts of a colourless interstitial base.

(*f*) Another variety is an aphanitic, olivaceous black, very fine-grained basalt consisting of small micro-insets of olivine and plagioclase in a very dense groundmass of slender laths and crystallites of feldspar, augite, and much dusty magnetite [927, 977]. One rock of this kind contains a large xenocryst 15 mm. across, of glassy feldspar

[GN 926]. There are several specimens of this kind varying a little in the size of olivines and feldspars and in the grain-size of the groundmass [GN 1034, 1066].

(*g*) A vesicular aphanitic olivine-basalt with small insets and micro-insets of very pale yellow, nearly colourless, olivines and occasional small insets of pale buff augite has a dark groundmass consisting mainly of closely packed stoutish laths of labradorite (An_{55-60}). Between the feldspar is fine-grained granular augite, perhaps a little olivine, and much opaque 'ore' [GN 991]. The colour is deep neutral grey and the well-rounded vesicles are quite empty. Another specimen of the same type shows the reddening and characteristic alteration of olivine noted in so many of the specimens from this moraine [GN 1028].

(*h*) Several specimens of these reddened lavas are fine-grained, aphanitic, 'sandy' rocks with the characteristic brownish-drab colour. Under the microscope they show rare small insets of the altered, opaque olivine in a groundmass of tiny laths of labradorite (near An_{55}), with much opaque deep brown augite, doubtful olivine, and magnetite.

(*i*) Among all the specimens of volcanic rocks from this moraine there is only one representative of an olivine-free basalt and that occurs as subangular fragments, 1 cm. or more across, in a tuff [GN 955]. The thin section shows small insets and micro-insets of pale purple-drab, zoned augite in a very dense groundmass. The groundmass consists of microliths of plagioclase in a pale brown to fawn-coloured glass crowded with minute augites (perhaps some very small olivines) and magnetites. There is some occult feldspathoid in the glass base. Magnetite as small micro-insets is a notable accessory.

Several specimens were collected by Priestley to illustrate xenoliths in these lavas. They generally prove to be xenoliths of quartzose sedimentary rocks of the same kind as some rocks in the slate-greywacke formation of Robertson Bay [GN 944].

For the Newnes Glacier it only remains to record that there are two specimens of a friable orange-coloured palagonitic tuff. This is rather similar to the tuffs of the Murray Glacier moraines which are described below (p. 145).

The Murray Glacier

Specimens of volcanic rocks were collected from two different parts of the Murray Glacier. The greater number come from the southern lateral moraine but a dozen specimens of volcanic rocks are from morainic material in the so-called 'Dry Valley', a low plateau over a mile broad left by the glacier at a time when part of its ice poured out south of Duke of York Island. The main stream now goes out on to the Dugdale Ice Tongue on the other side of the island (see Priestley, 1923, pp. 15–16 and plates 14 and 15).

Of the specimens from this 'Dry Valley' moraine nine are of basalt-tuffs and one is an aphanitic black basalt. Volcanic rocks collected from the southern lateral moraine comprise fourteen specimens of the basalt-tuffs and ten of a porphyritic olivine-basalt with very fresh green olivine a conspicuous constituent. These basalts will now be described.

Olivine-basalts

The most common basalt from the lateral moraine is a grey chrysophyric basalt characterized by abundant insets of fresh olivine and augite. The general colour of these rocks varies from light greyish olive to mouse-grey, and in a few specimens deep brownish drab. The olivine insets are light yellowish olive to olive-yellow and, in some specimens, dark greenish black and iridescent. The olivines range up to 1 cm. in length and the augites are only a little less, 6 mm. The augites are dark greenish black. In thin section the olivines are almost colourless and the augites very pale olive-buff. The extinction angle in the augites, $c:\gamma$, is up to 47°.

In the specimens with the coarsest-grained, holocrystalline groundmass there are no crystals ranking as micro-insets and the groundmass consists of plagioclase laths and small olivine crystals, with smaller augites and crystal grains of opaque 'ore'. The texture is intergranular [1160]. From this type there are gradual variations of the groundmass texture and grain-size. For example in 1178 in addition to the abundant insets of olivine and augite there are a few micro-insets of plagioclase. The groundmass consists of plagioclase laths, small olivines and augites, and fairly abundant crystals and blades of opaque 'ore'. The fabric of this groundmass is seriate in the sense that while it contains abundant plagioclase laths, olivine, and augite of about 0·05 mm. average diameter, there is interstitial to this larger feldspar mesh a base of much smaller crystals of olivine and augite and plagioclase and crystals and blades of opaque 'ore'. The opaque crystals referred to as blades are probably ilmenite. In some sections dark patches mark concentrations of these bladed crystals in the groundmass [1159], and the blades are more abundant than the more quadrate crystal grains of magnetite(?).

Increase in the proportion of opaque 'ore', the bladed crystals generally predominating, leads to darker holocrystalline groundmass, and, in specimens with very fine-grained groundmass, the constituent minerals are hardly resolvable. Examples of actual glassy groundmass were not found nor was actual or occult feldspathoid detected.

Another variation is that specimens with very fine-grained dark base carry micro-insets of plagioclase and small crystals of olivine and augite as well as the very abundant larger insets of these minerals [1168, 1125]. The feldspar in these basalts is labradorite near An_{65}.

The only other basalts collected from the southern lateral moraine appear to be fragments from the basalt-tuffs. One of these [1131], a dark neutral grey aphanitic olivine-basalt, occurs as fragments in a smoke-grey fine-grained matrix of volcanic tuff.

Another basalt from the same moraine [1157], unfortunately only now represented by two thin sections, contains abundant short laths of plagioclase in a dense black glassy base. Half-hidden in the glass are small micro-insets of olivine and augite, both rather rare. It seems possible that this might resemble the black glassy basalt (Type A) *in situ* at Cape Adare. The sections of this rock are interesting as they show sections of small oval bodies that appear to be xenoliths, consisting now largely of sillimanite with a little dark green spinel, as small octahedra, and some feldspar at the margin of the xenolith.

A black aphanitic olivine-basalt [1066] from the moraine in the 'Dry Valley' is rather like one of the basalts, lettered (*f*), from the Newnes Glacier. This contains a white granular patch 2 cm. across with scattered white crystals around it.* The thin section of the basalt shows many micro-insets of colourless olivine and a few of augite in a very fine-grained groundmass of abundant plagioclase laths and small, brown-stained olivines in a fine-grained dark base. The base is rather variable in density and is roughly banded, some parts being lighter coloured than others. In the lighter parts it can be seen that the groundmass consists of very small microliths of feldspar among abundant small magnetite crystals and augite granules, with a few small olivines, recognizable as apart from the augite by the yellow colouration.

Palagonite-tuffs

The rocks referred to above as basalt-tuffs, of which some two dozen specimens were collected on the moraines of the Murray Glacier, all prove to be fairly typical palagonite-tuffs comparable with those from Sicily and from the Lahntal in Nassau.

Some of the tuffs are fairly even-grained and, in hand-specimens, appear as if bedded. Most of them contain abundant dark lapilli of various sizes ranging up to 2·5 cm. in length, but few actually measure as much as 0·5 cm. across and most of them are only 1 or 2 mm. in diameter. Most of the larger lapilli examined are of basalt but a few are of dark very compact sedimentary rocks.

Thin sections show that the sedimentary fragments, usually subangular in form, comprise fine-grained greywacke and micaceous siltstone. Occasionally the greywacke type contains wisps of chlorite, indicating a low grade of metamorphism. Such sediments might be derived from the Robertson Bay slate-greywacke formation.

As for the basalt lapilli, some are black glassy basalts with very small, altered olivines, augite and abundant plagioclase laths [1075]; others are glassy limburgitic basalts with many crystals of olivine and augite and relatively few of feldspar [1158]. These latter show very many small spherical vesicles and similar 'bubbles' are still more abundant in the small lapilli of pale yellow basalt-glass that actually constitute the greater part of all these tuffs. These glassy lapilli contain many feldspar microliths and abundant fragments of olivine and some of augite. The colour of the glass is pale yellow.

The great abundance of tiny 'bubbles' in the yellow glass is very remarkable. Their frequency is comparable with that of the bubbles in some of the silica-glasses of meteoritic origin, where they are taken to indicate very high fluidity and very rapid cooling of a frothy glass. Some of these little vesicles in the lapilli are empty but some are filled with clear colourless carbonate and very many are either lined or filled with a slightly turbid, isotropic material a little darker in colour than the surrounding glass. This material often shows concentric arrangement and there are traces of radial fibrous structure in the outer lining.

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* Fragments from this patch are plagioclase feldspar near oligoclase, but the inclusion was not fully investigated. The refractive indices are near 1·53.

The matrix of most of these tuffs consists of comminuted glass and fragments of augite and of olivine crystals. Sometimes the glass of the matrix seems to merge with that of the lapilli themselves. In one specimen [1060] the matrix is clear, partly granular calcite and the lapilli, all very small, are almost all of the pale yellow glass. Only a few are of black glassy basalt, and sedimentary fragments seem to be rare.*

One rounded basalt fragment [1134] is an amygdaloidal very fine-grained olivine-basalt in which all the abundant vesicles are filled with carbonate. In many vesicles the carbonate has a radial structure and sometimes prismatic habit suggesting aragonite. Also parts of the vesicles are occupied by pinkish cinnamon isotropic material perhaps similar to that in the vesicles in the lapilli. It seems likely that this basalt is only one of the larger lapilli from the tuffs.

If found *in situ* much more time could be profitably spent in the study of these interesting palagonite-tuffs; indeed there is ample material for more work on the samples Priestley collected, but an end must here be made to this account of them.

VII. COMPARISON WITH VOLCANIC ROCKS FROM SOUTH VICTORIA LAND

Some of the basalts and some of the trachytoid phonolites found at Cape Adare show fairly close resemblances with rocks from other areas in South Victoria Land and from the off-shore islands.

Rocks from Possession Islands, which lie about 60 miles to the south of Cape Adare, were collected on the first voyage southward of Sir James Clarke Ross's Antarctic Expedition of 1839–43 and these were described by G. T. Prior (1899, p. 75). Others collected by C. E. Borchgrevink and Captain Jenssen in 1895 were described by Edgeworth David and others (1896, p. 484), and Prior (1902, p. 326) described the specimens collected on the Southern Cross Expedition in 1898. Some of the basalts *in situ* are similar to the porphyritic olivine-basalts with insets of augite and occasional brown hornblendes such as those described from the pseudo-cave on Cape Adare (p. 118).

A few specimens have been collected from Coulman Island, about 150 miles south from Cape Adare, and many pebbles were brought up in dredges off its shore. Little has been published about these specimens. Those collected by H. T. Ferrar, on 15 January 1902, 40 or 50 feet above their landing place at Cape Wadworth at the north end of the island are dense, aphanitic, black glassy basalts, or basanites. They are not of the same kind as any of the described basalts from Cape Adare. They are extremely fine-grained and contain abundant microliths of plagioclase and many small brown pseudomorphs after olivine, and small magnetites in a pale glassy base with minute blades and grains of opaque 'ore'. The HCl-etch solution test shows that feldspathoid is occult in the colourless base. These rocks [B.M. 87171, 75, 76, and 81] may be glassy equivalents of a basalt like the black basalts of Type A on Cape Adare.

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* Similar tuffs with very vesicular pale yellow basalt-glass lapilli in a calcareous cement are known from the volcano of Low Layton, west of Port Antonio, St. George's, Jamaica. According to Dr. C. T. Trechmann (A New Explanation of Mountain Uplift, 1955, p. 33), the Low Layton lava 'flowed out into a bed of one-time wet and sludgy Globigerina marls of late Miocene age'. It would be interesting to find under what conditions the calcareous palagonite-tuff was formed in the Cape Adare district.

Some of the dredged pebbles are very fine-grained aphanitic basaltic rocks and these also may resemble some Cape Adare basalts. Several other pebbles from dredges at depths between 8 and 15 fathoms off Cape Adare and about a mile west of Coulman Island are phonolitic trachytes or trachytoid phonolites bearing a general family likeness to the phonolitic rocks found as pebbles on Cape Adare beach, and some may compare with the trachytoid phonolite *in situ* there.

Admittedly there is ample room for more detailed work when more material is available but such comparisons as have been made are sufficient to confirm Priestley's description of Cape Adare (1923, p. 8) as 'the northward extension of the great volcanic series of rocks which appears to form the coast from Cape Phillips northwards along the mainland of South Victoria Land, and of which Coulman Island and Possession Islands form a part'.*

Looking further afield for comparisons, on Ross Island and the neighbouring smaller islands one finds that the trachytoid phonolite of Cape Adare [231], compares tolerably well with some variations of the trachytoid phonolite (Mount Terror type). Examples of such comparable types are specimens from the neighbourhood of Mount Terror and Cape Crozier [B.M. 87171, 243, and 251]† and other comparisons can be found among the trachytoid phonolites from Tent Island [D52E] and the Razorback Islands in the Dellbridge Group [B.M. 87171, 573 and D28E]. However, these lavas from the Dellbridge Group contain only a few micro-insets of pyroxene, hornblende insets are not much in evidence, and the proportion of dark minerals to light is high compared with the Cape Adare trachytoid phonolite.

The debris heap on Minna Bluff, about 50 miles to the south of Ross Island, provides another trachytoid phonolite [613] comparable with the one represented by many pebbles on Cape Adare beach (p. 138), and, as mentioned above (p. 136), another of the boulders from Minna Bluff [622] is somewhat similar to the porphyritic phonolite pebbles from Cape Adare. Another comparison made above with a Cape Adare pebble is one of the rocks recorded by Jensen as 'trachyphonolite' from Cape Bird (1916, p. 119), and other comparisons might be found among Ferrar's specimens from Brown Island.

---

* Cape Phillips is a little north of Coulman Island.

† It is interesting to note, *à propos* of the remarks above on Coulman Island, that Prior had noticed a close comparison between one of the Mount Terror phonolitic trachytes and one of the pebbles dredged off Cape Wadworth. He also compared basalts from Coulman Island with a 'hornblende-basalt' from Mount Terror (1907, p. 115, and plate 8, fig. 4).

Again among the basalts some comparisons can be made between some of the hornblende-bearing basalts of Cape Crozier and from Cape Bird at the south end of Ross Island on the one hand, and some of the porphyritic olivine-basalts with hornblende from Cape Adare on the other.

The general characters of these basalts from Cape Crozier and Cape Bird were described briefly in the report on the volcanic rocks of the Ross Archipelago (1954, p. 81). It should be noted that many of the 'hornblende-basalts' from Cape Bird described by H. I. Jensen (1916, p. 121) have insets of labradorite as well as of augite, and moreover they show few or none of olivine.

Among the basalts from Hut Point Peninsula on Ross Island several of the olivine-basalts with small insets of augite and olivine (Campbell Smith, 1954, p. 76) are closely allied to the porphyritic olivine-basalts of Cape Adare, and also some of the Hut Point basalts of the type described by Prior (1907, p. 102) as 'hornblende-basalts' are similar to some of the Cape Adare hornblende-bearing types. The general impression one gets by comparing the olivine-basalts of the two areas is that the Hut Point basalts all contain more abundant olivine insets than any of those from Cape Adare.

Such comparisons as have been made above would have more force were they backed by chemical analyses and by more detailed descriptions of the individual specimens described. However, perhaps sufficient resemblances have been established to suggest a relationship between the Cape Adare lavas and some of the volcanic rocks from the outlying parts of the Ross Island coast, though not with known volcanics from the main central mass around Mount Erebus.

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Fig. 4. Weathered 'variolitic' phonolite, Cape Adare (p. 124). Photographs by Staff-Surgeon G. Murray Levick.

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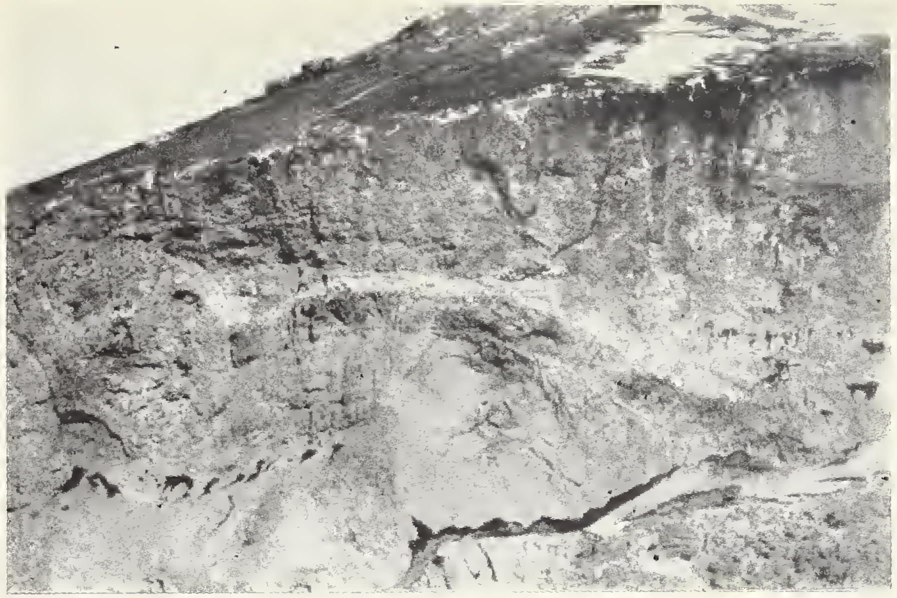


Fig. 1. Cliff at the northern end of Cape Adare. The boulder-bearing agglomerate is in the centre.

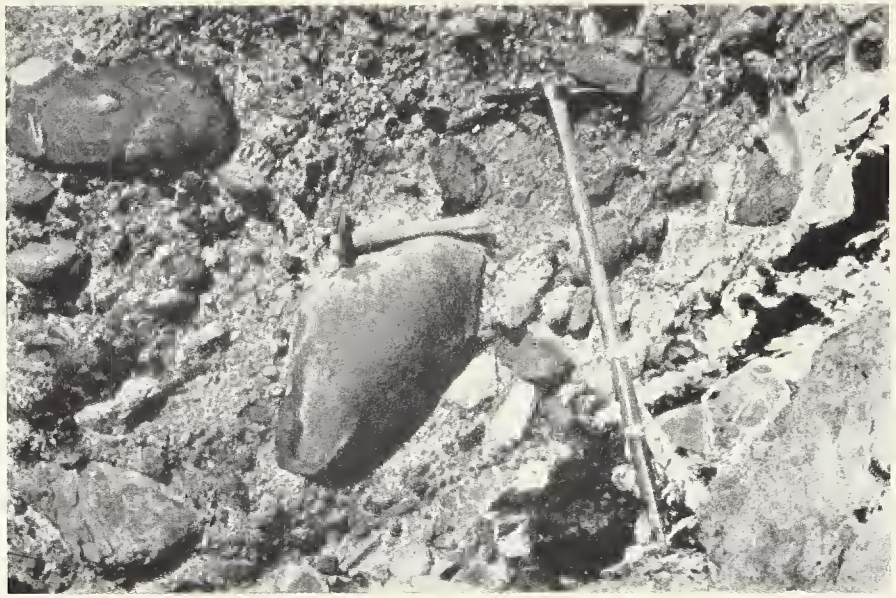


Fig. 2. The boulder-bearing agglomerate at Cape Adare.

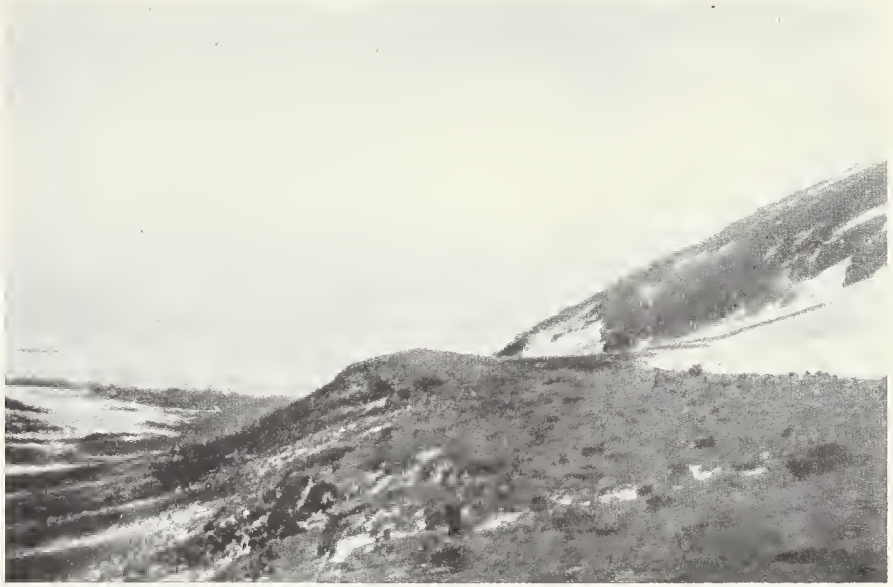


Fig. 3. The beach platform under Cape Adare. Part of Ridley Beach is seen beyond the end of the terrace.

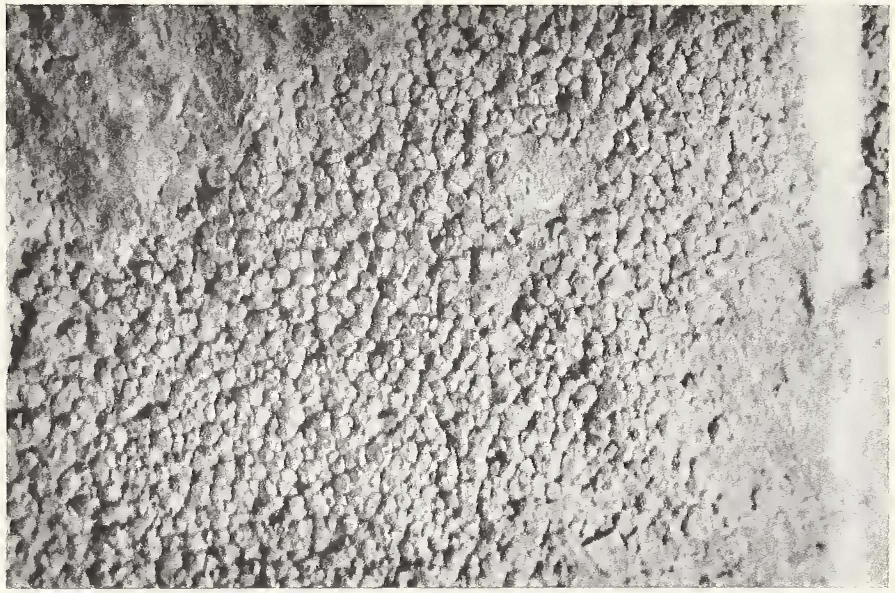


Fig. 4. Weathered 'varioloitic' phonolite. Cape Adare.

Photographs by Staff-Surgeon G. Murray Levick.

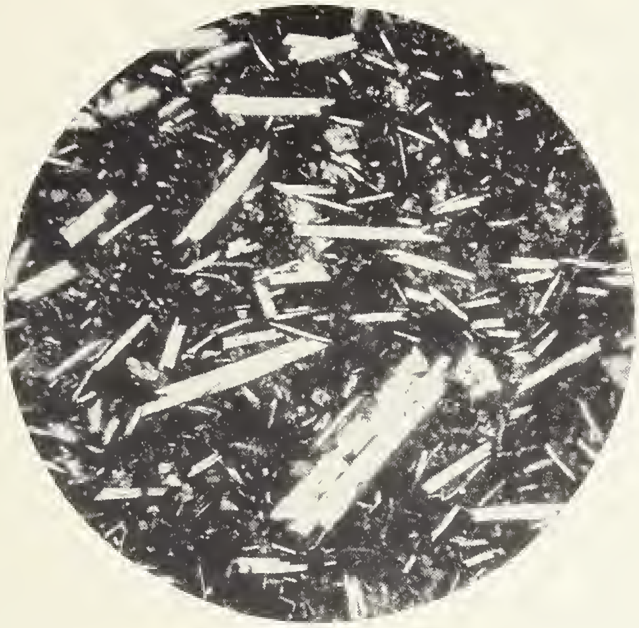
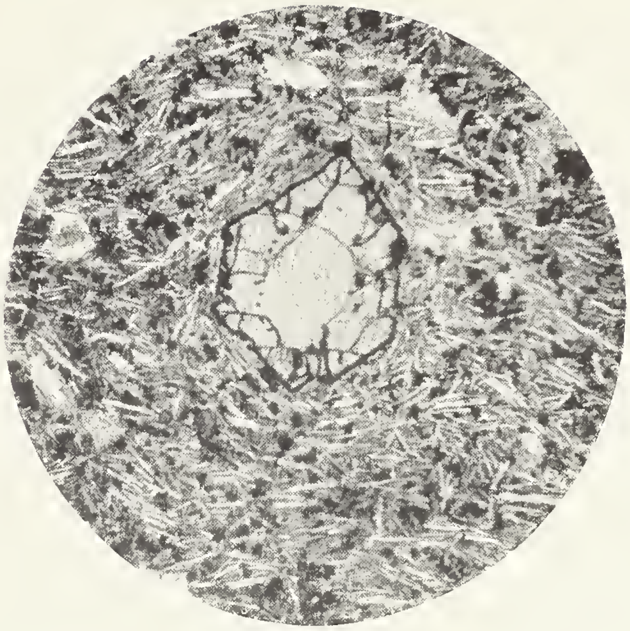


Fig. 1



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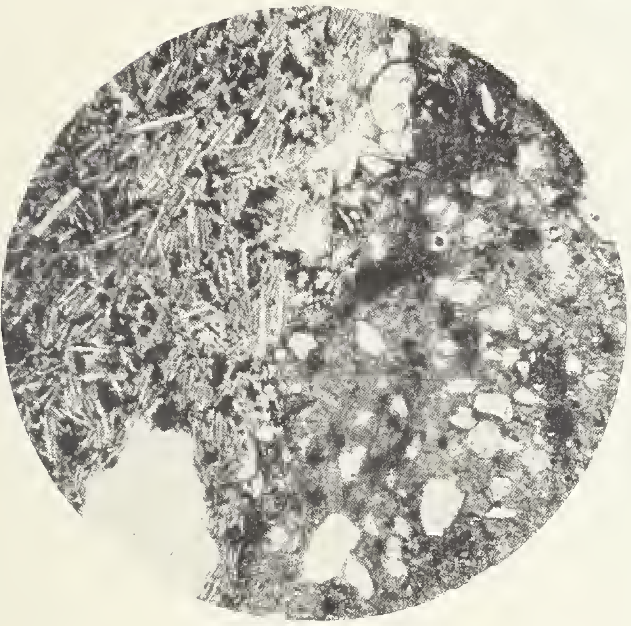

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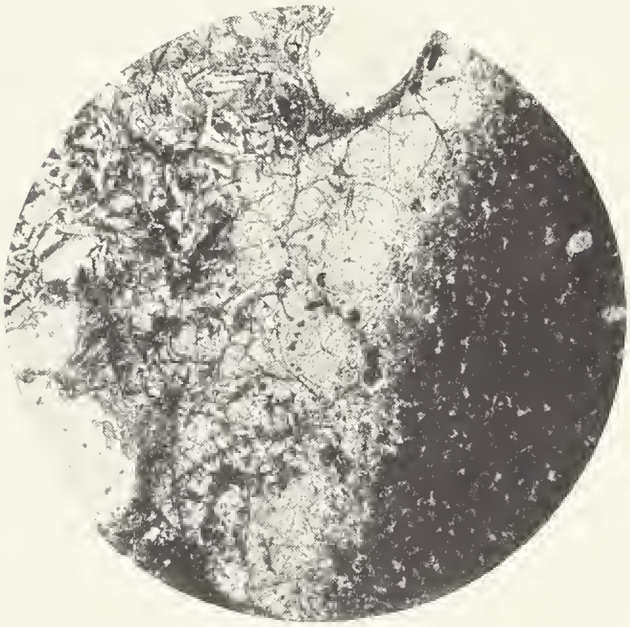

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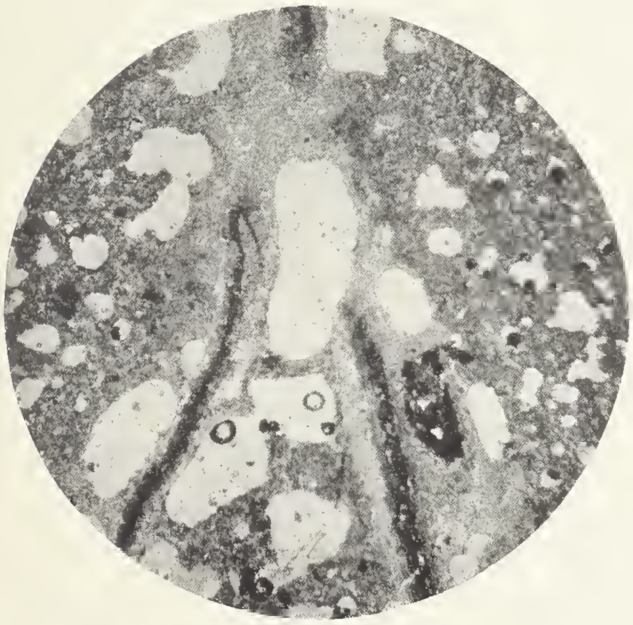

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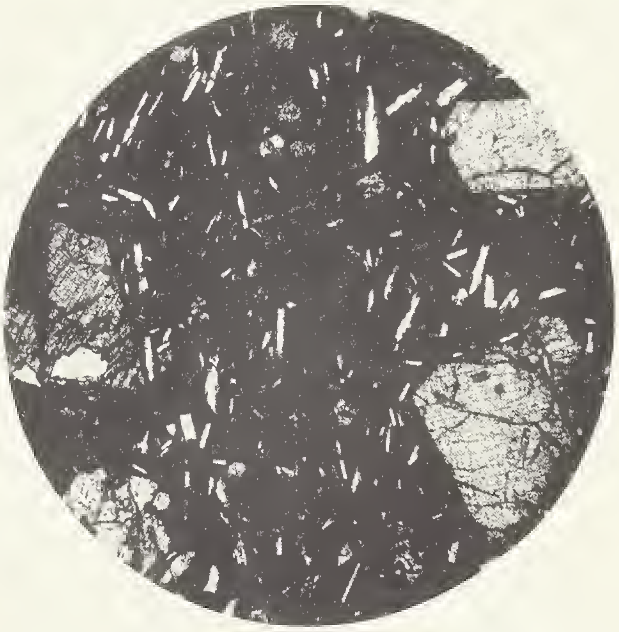

Fig. 6

B. M. (Nat. Hist.), photo.

OLIVINE-BASALTS AND INCLUDED XENOLITHS
FROM CAPE ADARE

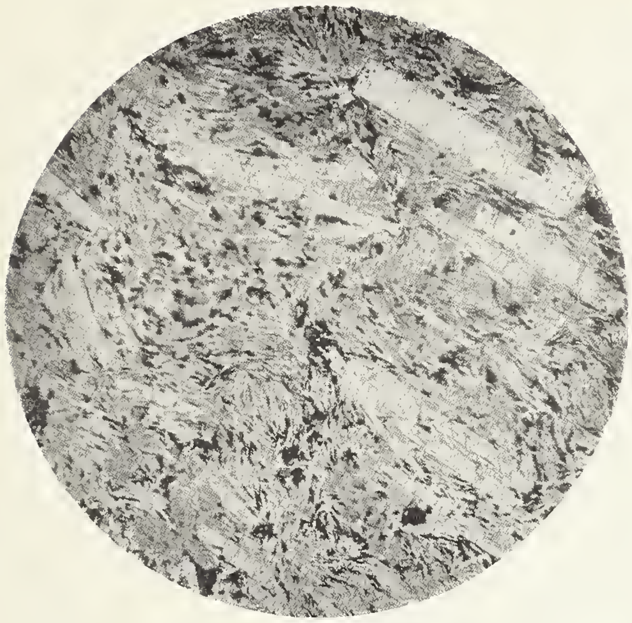

Fig. 1

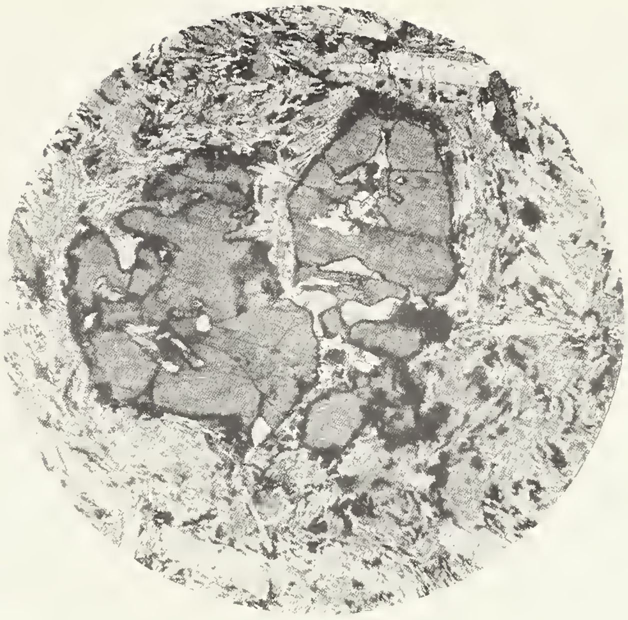

Fig. 2

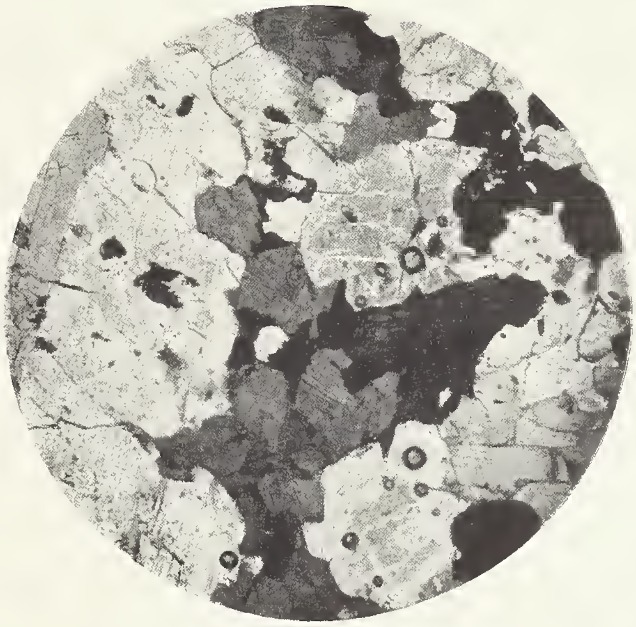

Fig. 3

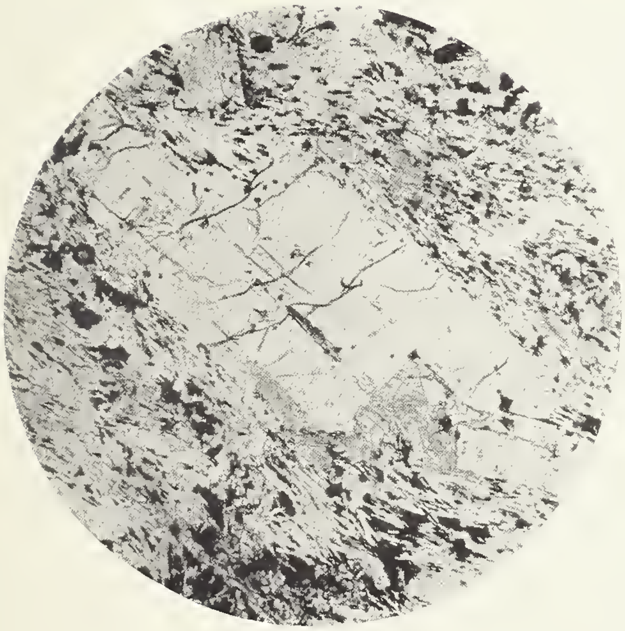

Fig. 4

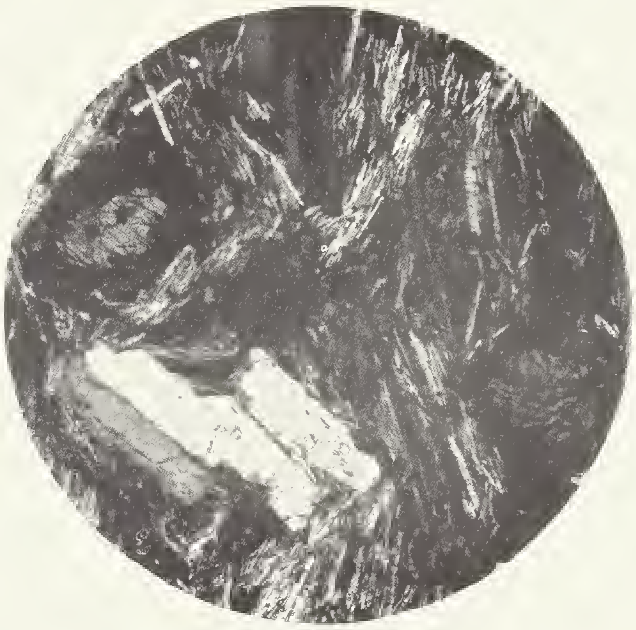

Fig. 5

B. M. (Nat. Hist.), photo.

ALKALI-TRACHYTES, SODALITE-TRACHYTES,
AND SANIDINITE FROM CAPE ADARE

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GEOLOGY. VOL. II. No. 3. Pp. 151—206

VOLCANIC ROCKS OF CAPE ADARE AND ERRATICS FROM TERRA NOVA BAY REGION, ETC.

BY

W. CAMPBELL SMITH

WITH ONE FIGURE IN THE TEXT AND ONE PLATE

LONDON:

TRUSTEES OF THE BRITISH MUSEUM (NATURAL HISTORY).

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[*Issued* January, 1964]

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I. CHEMICAL COMPOSITION OF VOLCANIC ROCKS OF CAPE ADARE

Chemical analyses have been made of seven of the rocks from Cape Adare described in the previous number of these reports. Three are of basalts, three of phonolites, and one of a sanidinite from the boulder-bearing agglomerate on the northern face of the cliff at Cape Adare. These analyses have been made by Mr. D. I. Bothwell in the Department of Mineralogy, British Museum (Natural History). They were not available when the petrographical descriptions of the rocks were written, and, in the light of the results of the analyses, some comments on and amendments to those descriptions are now called for. The analyses are tabulated in columns, 33 to 40 of Tables VIII and IX, and X and subsequent tables give the C.I.P.W. norms, the cation per cent composition, and 'basis' of Niggli and Burri in conformity with the tables in No. 1 of this volume in which the volcanic rocks of the Ross Archipelago are described. The 'Niggli values' are tabulated in Table XII (p.165).

Olivine-Basalts

On the basis of their characters as seen in hand-specimens and thin sections the Cape Adare basalts were divided into three types: A. Black, glassy, aphanitic olivine-basalt; B. Dark grey, holocrystalline olivine-basalt; and C. Porphyritic olivine-basalt with insets of augite and olivine.

The first point that emerges from a consideration of the analyses of the three olivine-basalts is the close similarity in composition between Types A and C (Nos. 432 and 245). The two types were distinguished mainly on account of the differences in fabric, Type A (p. 115) being compact and aphanitic, with a partly glassy groundmass, and Type C (p. 118) being porphyritic, with insets of augite and olivine, and occasional xenocrysts of brown hornblende, in a dense, black groundmass with glassy lustre. The analyses show that in chemical composition these two types are very similar. The normative composition also is very similar. The percentage of femic minerals is a little higher in Type C. The normative plagioclase in Type A (432) is An_{54}, in Type C (245) An_{56}, *or* and *ne* are both slightly higher in Type A than in Type C.

Compared with chemical analyses of other South Victoria Land basalts the closest match is presented by a basalt from Sulphur Cones, Hut Point Peninsula, described by Prior as "hornblende-basalt" [B.M. 87171, 385] and re-described in the preceding number of this volume (p. 79). In fact the two rocks are not closely alike in mineral composition, and the closest matches among the Ross Island basalts for the Cape Adare Types A and C seem to be the basalts of Cape Barne, described in the first place by Jensen from specimens collected on the British Antarctic Expedition, 1907–9, and re-described (p. 86) with an analysis by D. I. Bothwell (p. 99, No. 26a) from material collected by Frank Debenham on the Terra Nova Expedition.

The analysis of the Type B basalt (No. 392) shows slightly lower alkalies than Types A and C but the more striking differences are a high content of H_2O lost above 110°C. and the reversal of the Fe_2O_3:FeO relations, the Fe_2O_3 being in excess of FeO. This and the lower alkali-content induce notable differences in the calculated norms (Table VIII*a*), but in the 'Niggli values' the principal differences are the much higher *si*, compared with the *si* for Types A and C.

Plotted on the diagram based on variation of 'Niggli values' with *si* (this volume No. 1, Fig. 5, p. 92) one finds Type B at *si* 110·5 coming very close to a Cape Barne basalt [D24R] while types A and C at *si* 102 and 97 respectively fall on either side of the position of Jensen's basalt from Cape Barne [J4] (except for the *fm* value), and equally close to Prior's 'hornblende-basalt' from Sulphur Cones referred to above. As has been remarked already this 'hornblende-basalt' does not resemble, either in hand-specimen or thin section, the Type A and C basalts, but, contrariwise, there is a fairly good resemblance between the groundmass of Prior's 'hornblende-basalt' and that of the Type B olivine-basalt. It may be that the siliceous sedimentary xenoliths which the Type B basalt has partially digested has given the rock an abnormally high silica content and perhaps the high $H_2O+110°$ and the oxidation of such a high proportion of the ferrous iron in this basalt may be other effects of the same cause. A similar suggestion was made to account for the unusual composition of the Mount Cis 'trachyte' (this volume, No. 1, p. 93).

A description by Edgeworth David, Smeeth and Schofield of a pebble of a porphyritic olivine-basalt collected by C. S. Borchgrevink from the beach at Cape Adare in 1895 makes it probable that this specimen, though evidently much weathered, is of a rock similar to the olivine-basalt Type C (see No. 2, p. 120). However, the analyses (op. cit. p. 121, col. 1) of Borchgrevink's specimens shows very much higher MgO and CaO and much lower alkalies than in either the Type C or the Types A and B analyses.

TABLE VIII. CHEMICAL ANALYSES, NORMS, ETC. OF OLIVINE-BASALTS

33. Olivine-basalt, A. "III.6".4.4. 100 yards N. of northern limit of snow drift on Cape Adare. D. I. Bothwell, anal. [432=B.M. 1953, 91, 4]
34. Olivine-basalt, B. II (III).5"."3.4. Bluff near the end of upper beach platform, Cape Adare. D.I.Bothwell, anal. [392=B.M. 1953, 91, 40a].
35. Porphyritic Olivine-basalt, C. III.6.2(3).4. Cliff not far from Borchgrevink's Depot, Cape Adare. D. I. Bothwell, anal. [245=B.M. 1953, 91, 151].

TABLE VIII

a

Chemical Analyses

	33	34	35
SiO_2	44·1	44·5	43·2
TiO_2	3·3	3·2	3·8
Al_2O_3	16·7	15·8	15·7
Fe_2O_3	4·0	7·3	4·4
FeO	7·9	4·8	8·1
MnO	0·2	0·2	0·2
MgO	4·2	4·1	5·3
CaO	9·7	9·3	10·2
Na_2O	5·5	4·4	4·9
K_2O	2·4	1·6	2·0
H_2O+	1·0	2·0	0·9
H_2O-	0·1	0·9	0·1
P_2O_5	1·2	1·3	1·2
CO_2	—	—	—
ZrO_2	—	—	—
SO_3	—	—	—
SrO	—	—	—
Totals	100·3	99·4	100·0

b

C.I.P.W. Norms

	33	34	35
or	14·46	9·45	11·68
ab	10·48	27·25	11·53
an	13·62	18·63	15·01
ne	19·60	5·40	16·19
di	22·13	14·90	22·80
ol	4·32	2·38	5·41
mt	5·80	6·96	6·50
il	6·23	6·08	7·30
hm	—	2·56	—
ap	2·69	3·02	2·69

c

Cation per cent

	33	34	35
SiO_2	41	43·2	40·5
TiO_2	2·3	2·3	2·7
$\frac{1}{2}Al_2O_3$	18·2	18·0	17·7
$\frac{1}{2}Fe_2O_3$	2·8	5·4	3·1
FeO MnO	6·3	4·1	6·5
MgO	5·9	5·9	7·5
CaO	9·6	9·7	10·2
$\frac{1}{2}Na_2O$	10·0	8·3	8·9
$\frac{1}{2}K_2O$	2·9	2·0	2·4
H_2O+	—	—	—
H_2O-	—	—	—
$\frac{1}{2}P_2O_5$	0·9	1·0	0·9
Totals	100·0	99·9	100·4

d

'Basis'

	33	34	35
Cp	2·2	2·6	2·2
Ru	2·3	2·3	2·7
Kp	8·7	6	7·1
Ne	29·6	24·8	26·7
Cal	8·2	11·7	9·1
Cs	8·4	6·3	8·6
Fo	8·8	8·9	11·1
Fa	9·5	6·1	9·8
Fs	4·2	8	4·7
Q	17·9	23·2	17·8
Q	19	24	19
L	49	45	45
M	32	31	36
π	0·18	0·27	0·21
γ	0·27	0·21	0·25

In the π-k diagram (No. 1, fig. 7, p. 95) the points corresponding to Types A, C, and B (cols. 33, 35, and 34), fall (in that order) between No. 6, the trachytoid phonolite from Observation Hill, Ross Island, and No. 31 an olivine-basalt [D2F] from 'Black Hill' in the Ferrar Glacier region on the mainland.

The new analyses fill a gap in the series in this diagram and lie smoothly on a curve between the two points at its ends.

PHONOLITE AND TRACHYTOID PHONOLITES

The analysis given in column 36, Table IX, is of the remarkable phonolite with the 'variolitic structure' found at 900 feet above sea-level at Cape Adare [227]. This finds its nearest match among the analyses of volcanic rocks from South Victoria Land in the trachytoid phonolite [188] from Cape Crozier, analysed by G. T. Prior (No. 1, col. 3, Table I*a*). Comparison of the two rocks shows, however, that they bear no resemblance to each other in mineral composition. Nothing comparable to this compact phonolite from Cape Adare has been described among the Ross Island volcanics, so for the present it stands alone.

The analysed specimen of the trachytoid phonolite [584] is an erratic from the plateau above Cape Adare. It is a rock of the same kind as one [231] collected at 900 feet above sea-level on the Cape and described in this volume (No. 2, p. 125). Its chemical analysis, given in column 37, Table IX, finds a tolerably close match in an analysis by Prior of a 'phonolitic trachyte' from Scott Island [B.M. 87171, 973] quoted in column 4, Table Ia (No. 1, p. 37).

By comparison the analysis of the Cape Adare trachytoid phonolite shows lower Al_2O_3 and FeO, but higher Fe_2O_3 and more H_2O lost above 110°C. The differences in the 'Niggli values' are in the same sense, that is lower *al* and *fm* for the trachytoid phonolite but also it has higher *alk*, 32·5 as against 30.(1)

In thin section the Scott Island rock and the Cape Adare trachytoid phonolite appear to be roughly similar in mineral composition. Comparison suggests that there are more feldspar micro-insets in the Cape Adare rock, while in the Scott Island 'phonolitic trachyte' of Prior there is more brown hornblende and perhaps more magnetite (?), which occurs as occasional micro-insets as well as in the groundmass.

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(1) The 'Niggli values', and also the other values, except the analysis and the C.I.P.W. norms given for the Scott Island phonolitic trachyte given in col. 4 of Tables Ic–f are incorrect. The correctly calculated Niggli values are given in Table XII and corrections have also been supplied on a sheet of Errata for No. 1. of this volume.

The Scott Island rock in hand-specimen is compact, fine-grained, deep olive-grey⁽¹⁾ in colour, and it breaks with an undulating platy fracture. The thin section shows frequent micro-insets of simply twinned alkali-feldspar and faintly purplish, green-rimmed pyroxene prisms, as well as a few brown amphiboles and magnetites (as already mentioned). These micro-insets lie in a groundmass consisting of laths and plates of alkali-feldspar, with granules of a nearly colourless, or faintly yellow pyroxene and also plates of a pale green pyroxene, very small crystals of magnetite (?) and small areas of a colourless birefringent base that may be feldspathoid.

It is difficult to understand why H. S. Washington classified this analysis as 'trachydolerite' (1917, p. 573, No. 40),⁽²⁾ but he had only the analysis to go on as Prior had not published any detailed description of the rock. It is to remedy this position that the above brief description of the rock is included here.

The third analysis (No. 670, col. 38) is of one of the boulders of sodalite-trachyte from the 'agglomerate' on the northern face of Cape Adare, described in the preceding number of this volume (pp. 127–8). The analysed specimen is representative of the rocks there described, except that olivine, recorded as an occasional constituent in these rocks (p. 128), is very rare in the thin sections of the analysed specimen. Also it is evident from the low Cl′ that sodalite forms only a small percentage of the mineral composition.

None of the analysed phonolitic trachytes from South Victoria Land are at all near this sodalite-trachyte in composition. In the variation diagram based on the 'Niggli values' it falls, owing to its *si* value, near the two analysed Mt. Cis 'trachytes', but its other values do not fit in at all well with these. Comparing thin sections of the two rocks one notes that the Mount Cis trachyte contains fewer insets, its green pyroxene is relatively poorly developed, and the feldspar laths of the groundmass are much more slender and more closely packed. However, I have recorded probable sodalite, both as small colourless cubes (p. 24) and as interstitial material between the feldspars (p. 23) in the Mount Cis 'trachyte' which is another point of resemblance with the sodalite-trachytes. As remarked above (p. 25 and p. 93) the Mount Cis 'trachyte' analyses may have unusual composition owing to partial assimilation of so many inclusions of Beacon Sandstone in the 'trachyte', so that the *si* values may be relatively high.

It is of interest to note a rather remarkably close similarity between the chemical analysis of the sodalite-trachyte [670] and that of the hedrumite from between Sundet and Delingsdal on Lake Åsrum, east of Lougenthal, Hedrum,

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(1) Names used for colours are based on 'Color standards and color nomenclature'. By R. Ridgway. Washington, 1912.

(2) References given by date and page in parentheses refer to the list on p.149 of No. 2 of this volume.

in the Oslo region, described by W. C. Brøgger⁽¹⁾. The modal mineral composition of the two rocks is also very similar but they differ notably in texture, the hedrumite, a dyke, being a medium- to coarse-grained rock with trachytic structure, whereas the sodalite-trachyte is fine-grained and porphyritic. This contains more nepheline than some hedrumites described by Brøgger. The mode calculated by Brøgger shows 7·3 per cent nepheline, and according to Johanssen 'the pyroxene is predominantly aegirite with subordinate aegirite-augite';⁽²⁾ also the brown mica, lepidomelane, the predominant coloured mineral in the Skirstad and Ostö hedrumites is very subordinate (3%) to the pyroxene.

TABLE IX. CHEMICAL ANALYSES, NORMS, ETC. OF PHONOLITES

36. Phonolite. 'II.6.1.4.
900 feet above sea-level, Cape Adare.
D. I. Bothwell, anal. [227=B.M. 1953, 91, 316].
37. Trachytoid phonolite. "II."6.1.4.
Erratic from plateau on the top of Cape Adare.
D. I. Bothwell, anal. [584=B.M. 1953, 90, 57].
38. Sodalite-trachyte. II'.(5)6.1'.4.
Boulder from the 'agglomerate' on northern face of cliff, Cape Adare.
D. I. Bothwell, anal. [670=B.M. 1953, 90, 82].

TABLE IX

a

CHEMICAL ANALYSES

	36	37	38
SiO_2	56·2	55·5	59·2
TiO_2	0·2	0·6	0·2
Al_2O_3	18·7	18·2	17·5
Fe_2O_3	3·0	3·9	3·9
FeO	1·8	3·0	2·1
MnO	0·2	0·2	0·2
MgO	0·3	0·9	0·4
CaO	1·6	3·6	1·6
Na_2O	9·4	8·1	8·2
K_2O	5·3	3·9	5·6
H_2O+	2·7	1·2	0·6
H_2O-	0·3	0·3	0·1
P_2O_5	0·1	0·2	0·1
Cl'	—	—	0·3
TOTALS	99·8	99·6	100·0

b

C.I.P.W. NORMS

	36	37	38
Q	—	—	—
or	31·14	22·80	33·36
ab	26·86	40·87	37·20
an	—	1·67	—
ne	21·51	15·05	11·64
hl	—	—	0·47
ac	8·78	—	7·39
ns	0·73	—	—
di	6·5	7·98	6·18
wo	—	2·78	—
ol	0·51	—	0·35
mt	—	5·57	1·86
il	0·46	1·22	0·46
ap	0·23	0·50	0·34

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(1) Brøgger (W. C.). Die Eruptivgesteine des Kristianiagebietes. III. Das Ganggefolge des Laurdalits. 1898, pp. 185–6, and p. 192.

(2) Johannsen (A.). A descriptive petrography of the igneous rocks. Vol. 4 (1938), p. 26.

TABLE IX (continued)

c

CATION PER CENT

	36	37	38
SiO_2	51·2	51	53·7
TiO_2	0·16	0·44	0·2
$\frac{1}{2}Al_2O_3$	20	19·6	18·7
$\frac{1}{2}Fe_2O_3$	2·1	2·7	2·6
FeO			
MnO	1·5	2·5	1·74
MgO	0·4	1·25	0·05
CaO	1·6	3·6	1·6
$\frac{1}{2}Na_2O$	16·7	14·4	14·35
$\frac{1}{2}K_2O$	6·1	4·5	6·5
H_2O+	—	—	—
H_2O-	—	—	—
$\frac{1}{2}P_2O_5$	0·08	0·16	0·1
TOTALS	99·8	100·15	99·5

d

'BASIS'

	36	37	38
Cp	0·17	0·4	0·3
Ru	0·16	0·4	0·2
Kp	18·4	13·5	19·6
Ne	41·8	43·3	36·5
Ns	4·1	—	3·3
Cal	—	1	—
Cs	2·25	4·5	2·15
Fo	0·6	1·8	0·8
Fa	2·3	3·7	2·6
Fs	3·1	4·0	3·9
Q	27·0	27·4	30·4
Q	27·1	27·6	30·6
L	60·5	58·5	56·5
M	12·4	14·1	12·85
π	0	0·02	0
γ	0·27	0·32	0·22

TRACHYTE AND SANIDINITE

Two further analyses enable one to extend the variation diagram (this vol., No. 1, fig. 5) beyond the *si* values of the 'sodalite-trachyte' and the Mount Cis phonolitic trachyte. These are analyses of one of the sanidinite blocks from the agglomerate on the north face of the cliff at Cape Adare described in the previous number of this volume (pp. 130–132), and a 'trachyte' collected at Cape Adare [from the beach?] by C. E. Borchgrevink in 1895 and described and analysed by Edgeworth David, Smeeth and Schofield (1896, pp. 473–4). The analyses of these two rocks are given in Table X and their calculated 'Niggli values' at the top of Table XII.

The description by Edgeworth David, Smeeth, and Schofield of the 'trachyte' is as follows:—

Trachyte (*Nos.* 1 *and* 2)

"Compact, greenish-grey in colour, somewhat fissile. Sp. gr. 2.49. Under the microscope the rock is seen to be composed principally of sanidine microlites. There is a small proportion of lath-shaped triclinic microlites and of crypto-crystalline interstitial material. The sanidines are apparently all tabular in form, some slices showing nothing but tabular sections while others yield only lath-shaped ones.

The ferromagnesian constituent is represented by an aegirine which is present in considerable quantity (probably nearly 25% of the whole bulk). It exhibits brownish-green to bluish-green pleochroism with a small extinction angle. It is uniformly distributed in minute angular patches moulded on the feldspars with here and there a tendency to an elongated prismatic habit. In places it shows ophitic structure on a small scale. The only porphyritic constituents are a few rounded grains of this same aegirine and a few large grains of magnetite.

As accessory constituents there are a number of minute flakes of a brown biotite, some needles of apatite included in the feldspars, a few zircons and a little magnetite."

Among the many pebbles collected from Ridley Beach (this volume, No. 2, p. 138) are two of phonolitic trachytes [355, 369] whose mineral composition and structure agrees fairly well with the above description of Borchgrevink's specimen, probably also a pebble picked up on the shore (op. cit. 1896, p. 468), but the high SiO_2 in the chemical analysis implies that in this case the rock is 'saturated' and nepheline is absent from the norm.

TABLE X. CHEMICAL ANALYSES, NORMS, ETC. OF SANIDINITE AND TRACHYTE

39. Sanidinite. (I)II.5.1.(3)4.
Boulder from the 'agglomerate' on northern face of cliff, Cape Adare. D. I. Bothwell, anal. [686=B.M. 1953, 90(95)].

40. Trachyte, Edgeworth David, Smeeth and Schofield, 1896. Washington, 1917, p. 430.
Pebble collected by C. E. Borchgrevink, 1895, from the beach at Cape Adare. J. A. Schofield, anal.

TABLE X

a
CHEMICAL ANALYSES

	39	40
SiO_2	60·6	61·01
TiO_2	0·5	—
Al_2O_3	17·3	16·62
Fe_2O_3	1·9	3·55
FeO	4·3	2·81
MnO	0·2	0·55
MgO	0·4	0·06
CaO	2·5	3·27
Na_2O	6·7	5·92
K_2O	5·4	5·22
H_2O+110	0·3	1·13
H_2O—	0·2	—
P_2O_5	0·1	tr.
Cl	0·03	tr.
less O for Cl		
TOTAL	100·1	100·14

b
C.I.P.W. NORMS

	39	40
Q	—	0·84
or	31·9	31·14
ab	46·56	49·78
an	1·12	3·34
ne	5·57	—
di	9·20*	6·63
wo	—	2·20
hy	—	—
en	—	—
ol	1·74*	—
mt	2·76	5·10
il	0·9	—
hm	—	—
ap	0·27	—

The *di* has $CaSiO_3$ 4·43 and $MgSiO_3$ 1·0:
*the *ol* is fayalite, Fe_2SiO_4.

TABLE X (continued)

c

Cation per cent

	39	40
SiO_2	55·3	56·5
TiO_2	0·33	n.d.
$\frac{1}{2}Al_2O_3$	18·58	18·15
$\frac{1}{2}Fe_2O_3$	1·35	2·45
FeO	3·24	2·17
MnO	0·15	0·44
MgO	0·54	0·11
CaO	2·45	3·23
$\frac{1}{2}Na_2O$	11·85	10·6
$\frac{1}{2}K_2O$	6·28	6·25
H_2O+	—	—
H_2O-	—	—
$\frac{1}{2}P_2O_5$	0·07	n.d.
Total	100·14	99·90

d

'Basis'

	39	40
Cp	0·2	—
Ru	0·3	—
Kp	18·9	19·8
Ne	35·5	32
Hl	0·1	—
Cal	0·7	2
Cs	3·3	3·9
Fo	0·8	0·02
Fa	4·9	3·3
Fs	2·0	3·7
Q	33·4	36·2
Total	100·1	100·02
Q	33·4	36
L	55·1	53
M	11·5	11
π	0·013	0·04
γ	0·3	0·36

The sanidinite [686], as remarked above, was described in the previous number of this volume, a chemical analysis of its feldspar was given (p. 131) and its composition and optical properties were there discussed. The accompanying minerals recorded were: "brown amphibole, green pyroxene, biotite, and some opaque 'ore' "; and unidentified minerals perhaps representing altered cancrinite appearing in some small interstitial area (footnote, p. 133). Since the publication of that description of the minerals further determinations of optical properties of the biotite and of the brown amphibole have been attempted with the following results. The biotite is biaxial with 2V at least 20°. The refractive index, γ is near 1·67. Comparable high values for γ are recorded for siderophyllite and also for several biotites with high FeO and low MgO. Larsen and Berman(1) quote one with $FeO+Fe_2O_3$ 38·4% having $\gamma=1·677$, while G. Schauberger(2) quotes an analysis for a mica, said to be from Brevik, as having γ 1·697, the FeO being 24·36% and Fe_2O_3 16·48 with MgO 1·08.

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(1) Larsen (Esper S.) and Berman (Harry). 1934. The microscopic determination of the non-opaque minerals. U.S. Geol. Surv. Bulletin 848, 1934, p. 238.

(2) Schauberger (G.). 1927. Biotit in tertiären Eruptivgesteinen Böhmens. Centr. f. Min., Abt. A., 1927, p. 103.

In the calculation of mineral composition from the bulk analysis below the mica is taken as almost pure annite which corresponds to the Fe-Biotite of Burri's conventional mica in the equivalent norm calculations.

The amphibole was found to have α' just above 1·716 and below 1·717 and γ' near 1·737 with extinction angle $c=\gamma$ 14°. The pleochroism is intense; α' cinnamon buff, γ' dusky olive-green. Owing to the high absorption a satisfactory measurement of the refractive index γ' is difficult to obtain. These properties indicate that the amphibole is probably referable to hastingsite and the high refractive indices point to its being near the ferrohastingsite end of this series as interpreted by Winchell.

A good example of a hastingsite with high refractive indices and high iron content quoted by Winchell (1) is a ferrohastingsite from rapakivigranite at Uuksunjoki, Salmi area, Finland: for which $a=1{\cdot}702$, $c\text{-}\gamma=12°$, 2V very small, and pleochroism, α pale greenish brown, β dark greenish brown, γ bluish green. The analysis of this amphibole shows Fe_2O_3 5·0, FeO 26·64, MgO 1·07. (Sahama, (2)). It is noteworthy that in the same rock the biotite has a and γ near 1·730 with 2V=22°.

For the composition of the feldspar we have the analysis by Mr. D. I. Bothwell referred to above. The sample was slightly impure and after allowing for this the composition arrived at was Or:Ab:An=36:62·6:1·4.

A further, rather rough, guide to the mineral composition of the sanidinite is provided by the relative proportions of feldspar to two fractions of magnetic coloured minerals as obtained in the magnetic separation used in preparing the feldspar sample for analysis. The separation was not originally made on a quantitative basis but the separate fractions were weighed later and showed:—

Non-magnetic; feldspar, 79·3%
moderately magnetic; amphibole and biotite, 17·2
most magnetic; magnetite, etc., 3·5

On calculating the 'basis' components from the analysis of the feldspar it was found that the ratio of Ne:Kp was 1·85. This is very close to the same ratio Ne:Kp for the sanidinite (Table X, col. 39) which is 1·88.

On starting to calculate the mineral composition from the 'basis' of the sanidinite it was decided to keep this Ne:Kp ratio as close as practicable to near 1·85–1·88, and this controlled the relative proportions of Ne to be allotted to the amphibole and pyroxene and of Kp to the biotite. The pyroxene was known to be aegirine-augite (p. 132). The biotite is to be calculated on Burri's formula for Fe–Biotite, $6SiO_2.Al_2O_3.6(Fe,Mg)O.K_2O.2H_2O$; and the amphibole as ferrohastingsite according to the formula: $NaCa_2(Fe,Mg)_4Al_3Si_6O_{22}(OH)_2$ which can be written:

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(1) Winchell (A. N.). Elements of optical mineralogy. Part II. 4th ed., 1951, p. 435.

(2) Sahama (Th. G.). Rapakivi amphibole from Uuksunjoki, Salmi area. Bull. Com. Geol. Finlande, 1947, No. 140. pp. 159–162.

$$12SiO_2.3Al_2O_3.8(Fe,Mg)O.4CaO.Na_2O.2H_2O.$$

The Fe–Biotite is derived from Kp according to the equation:

$$6Kp+9(Fe,Mg)O+1Q(+2W)=16 \text{ Fe-Bi.}$$

The Na_2O for the amphibole must be derived from Ne, and, in addition Na_2O for acmite must also be found, as no Ns is available. This can be provided according to the equation:

(1) $6Ne+3Fs+1Q=8Ac+2C$, or

(1′) $12Ne+6Fs+2Q=16Ac+4C$.

The ferrohastingsite is made up according to the equation:

(2) $6Ne+6Cs+12(Fa,Fo)+4Q(+2W)=32Fe\text{-}Ha.$(1)

Combining equation 1′ and 2 to eliminate 4C on both sides of the equation we have:

(3) $18Ne+6Fs+6Cs+12(Fa,Fo)+6Q(+2W)=32 \text{ Fe-Ha}+16Ac.$

The fact that the units of Ne in this combined equation number 18 made it easy to keep the Ne taken for amphibole and pyroxene at near 1·8 times the Kp used for biotite. In fact the ratio was only disturbed by the need to take 0·3 Fa to combine with 0·2 of the Ru for ilmenite.(2)

The calculation of the mineral composition follows the methods given by C. Burri (1959, p. 121 *et seq*).(3) The final results obtained, shown in detail in the adjoining table, are:

Or	Ab	An	Ne	Sod	Wo	Ac	Fe-Bi	Fe-Ha†	Mt	Il	Tit	Cp	Total
28·5	49·5	1·2	1·3	1	2·6	3·2	4·8	6·4	0·8	0·4	0·3	0·2	100·2

In the feldspars and feldspathoids the final ratio Ne/Kp is 1·86. Feldspar constitutes 79·2% of the whole rock, and its percentage composition in terms of Or:Ab:An=35·9:62·5:1·6, which, is in very close agreement with the composition deduced from feldspar analysis, *viz*: 36:62·6:1·4.

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(1) Fe–Ha=ferrohastingstite.

(2) See footnote to Table XI.

(3) Burri (C.). Petrochemische Berechnungsmethoden auf Äquivalenter Grundlage. 1959, p. 121. *et seq.*

TABLE XI

CALCULATED COMPOSITION OF THE SANDINITE

Mineral composition derived from Basis	Kp	Ne	Hl	Cal	Cs	Fs	Fo	Fa	Cp	Ru	Q	Totals
	18·9	35·5	0·1	0·7	3·3	2·0	0·8	4·9	0·2	0·3	33·4	100·1
6·4 *Fe*-Ha+3·2 Ac	–	3·6	–	–	1·2	1·2	2·4		–	–	1·2	9·6
4·8 *Fe*-Bi	1·8	–	–	–	–	–	2·7		–	–	0·3	4·8
1 Sodalite	–	0·9	0·1	–	–	–	–		–	–	–	1·0
0·4 Ilm [+0·1 Q]	–	–	–	–	–	–	0·3*		–	0·2	–	0·5
0·8 Mt [+0·4 Q]	–	–	–	–	–	0·8	0·4		–	–	–	1·2
2·6 Wo+0·3 Tit	–	–	–	–	2·1	–	–		–	0·1	0·7	2·9
1·2 An	–	–	–	0·7	–	–	–		–	–	0·5	1·2
28·5 Or	17·1	–	–	–	–	–	–		–	–	11·4	28·5
49·5 Ab	–	29·7	–	–	–	–	–		–	–	19·8	49·5
1·3 Ne	–	1·3	–	–	–	–	–		–	–	–	1·3
0·2 Cp	–	–	–	–	–	–	–		0·2	–	–	0·2
100·2+0·5 Q	–	–	–	–	–	–	–		–	–	–	–
—0·5 Q	–	–	–	–	–	–	–		–	–	—0·5	–
	18·9	35·5	0·1	0·7	3·3	2·0	5·8		0·2	0·3	33·4	100·2*

* 0·1 Fa in excess of the 4·9 available was added to avoid awkward arithmetic in calculating the hornblende, magnetite and ilmenite.

The Niggli values of all the analyses of the volcanic rocks from both Cape Adare and the Ross Archipelago are set out in Table XII in order of decreasing ***si***. It will be noticed that *qz* values differ from those given for analyses of Ross Archipelago volcanics in Tables I–VI in No. 1 of this volume. Those values were calculated incorrectly. The correct values are as now given in the last column but two of Table XII.

The collected analyses have been studied afresh using the variation diagram, the Q–L–M diagram and others illustrated in Figures 5–8 of the report on the Ross Island volcanics. In addition use has been made of a method employed by C. Burri in his recent study of the petrochemistry of the rocks of the Cape Verde Islands. This method introduced by A. Rittmann in 1933 plots on rectangular co-ordinates the 'Silicification-grade' (Si°) against the 'Acidity-grade' (Az°). These quantities, as defined by Rittmann, are calculated from the equations:

$$\mathrm{Si}^\circ = \frac{si}{100+4alk} \text{ if } al>alk; \text{ or } \mathrm{Si}^\circ = \frac{si}{100+3al+alk} \text{ if } al<alk$$

$$\mathrm{Az}^\circ = \frac{si}{si+al+fm+c+alk} = \frac{si}{si+100}$$

TABLE XII. 'NIGGLI VALUES' OF VOLCANIC ROCKS OF SOUTH VICTORIA LAND

	'Anal.'*	si	al	fm	c	alk	k	mg	ti	p.	c/fm	qz,	Si°	Az°
40. Sanidinite, C. Adare	D.I.B.	233	36·3	18·6	9·8	35·2	0·345	–	1·4	0·2	0·525	–8	0·97	0·70
39. 'Trachyte', C. Adare	J.A.S.	218	35	20	12·5	32·5	0·37	0·02	n.d.	n.d.	0·625	–12	0·95	0·69
2. Phonolite trachytic, Mt. Cis	H.	205	33·3	28·7	7·9	30·2	0·38	0·19	3·7	0·83	0·275	–15·8	0·93	0·67
38. 'Sodalite-trachyte', C. Adare	D.I.B.	204	35·5	18·6	6·0	39·75	0·313	0·11	0·62	0·2	0·32	–42	0·83	0·67
1. Phonolitic trachyte, Mt. Cis	D.I.B.	203	33	27	8·5	31·5	0·41	0·15	3·3	0·2	0·315	–23	0·90	0·67
5. Phonolitic trachyte, Brown I...	G.T.P.	200	45	6	5	43·5	0·33	0·13	0·8	–	0·83	–74	0·73	0·67
3. Trachytoid phonolite, C. Crozier	G.T.P.	192·8	40	14	6·5	39·5	0·32	0·1	1·0	0·1	0·465	–65	0·75	0·66
36. Phonolite, C. Adare	D.I.B.	190	37·2	14·8	5·9	42·2	0·27	0·095	0·6	0·2	0·4	–63·8	0·75	0·655
15. Kenyte (Jensen), C. Evans	H.	180	36·3	21·1	9·3	33·2	0·29	0·27	3·2	–	0·44	–52·8	0·77	0·64
16. 'Leucite-Kenyte' (Prior), C. Royds	G.T.P.	180	39	20	11	30	0·26	0·31	–	–	0·54	–40	0·82	0·64
14. Vitrophyric Kenyte, C. Evans	H	178·5	36	22	11	31·5	0·29	0·23	3·3	–	0·47	–47·5	0·79	0·64
37. Trachytoid phonolite, C. Adare	D.I.B.	175	33·6	21·8	12·1	32·5	0·24	0·225	1·5	0·2	0·55	–55	0·76	0·64
4. 'Phonolitic trachyte' (Prior), Scott I. ..	G.T.P.	172	35·3	23	11·6	30	0·24	0·1	1·5	0·17	0·5	–48	0·78	0·63
13. Kenyte, C. Evans	D.I.B.	172	36	20	11·8	32	0·29	0·25	–	–	0·59	–56	0·755	0·63
6. Trachytoid phonolite, Hut Pt.	G.T.P.	169	37	18	11	34	0·28	0·36	3·1	0·04	0·61	–67	0·72	0·63
17. Kenyte-pumice, Mt. Erebus	J.D.E.	158	34	24·2	8·5	33·2	0·24	0·21	–	–	0·35	–74·8	0·68	0·61
7. Trachytoid phonolite, C. Bird..	B. & W.	148	32·5	27	14	26·5	0·25	0·3	3·0	0·34	0·52	–58	0·72	0·60
23. Plagioclase-Kenyte, Turk's Hd.	H.	126	29	31	22	18	0·26	0·57	5·2	0·1	0·74	–46	0·73	0·56
22. 'Kulaitic Basalt', C. Bird	B. & W.	122	33·4	30	23·4	13·2	0·25	0·47	1·7	tr.	0·78	–31	0·80	0·55
24a. Basalt, Little Razorback I.	D.I.B.	118	24	38	22·5	14·5	0·21	0·39	0·55	1·65	0·59	–40	0·75	0·54
24. Hornblende-basalt (Prior), Mt. Terror ..	G.T.P.	116	29·5	32·5	20	18	0·24	0·34	1·2	0·88	0·61	–56	0·675	0·54
34. Olivine-basalt B., C. Adare	D.I.B.	110·5	23·1	39·1	24·7	13·1	0·19	0·4	5·9	1·3	0·71	–41·6	0·73	0·525
26a. Basalt, Cape Barne	D.I.B.	110	24	38	24	14	0·22	0·385	0·56	1·7	0·63	–46	0·705	0·52
33. Olivine-basalt A, C. Adare	D.I.B.	102	22·75	37·2	24	16	0·23	0·38	5·7	1·1	0·64	–62	0·62	0·505
27. Hornblende-basalt, Hut Pt. Pen.	G.T.P.	100	23·2	40·5	23·2	13·2	0·23	0·41	0·18	0·02	0·57	–52·8	0·65	0·50
26. Basalt, C. Barne	H.	100	21·6	46·2	21·75	10·4	0·23	0·48	0·86	0·01	0·47	–41·6	0·70	0·50
35. Olivine-basalt, C., C. Adare	D.I.B.	97	20·7	41	24·5	13·5	0·21	0·44	6·5	1·08	0·60	–57	0·63	0·49
30. Olivine-basalt, Cheyenne Crater	N.E.B. D.I.B.	91	19	48	25	8	0·21	0·48	0·6	–	0·51	–41	0·69	0·47
32. 'Leucite-tephrite' (Jensen), Hut Pt. Pen. ..	H.	89·3	17·4	51	25·8	6·3	0·30	0·55	0·73	0·08	0·51	–35·9	0·71	0·47
31. Olivine-basalt, Taylor Valley	D.I.B.	89·1	18	50	23	8·7	0·25	0·46	0·84	0·05	0·46	–45·7	0·72	0·47
29. Olivine-basalt, Hut Pt. Pen.	G.T.P.	87	18	49·5	23·5	9	0·27	0·55	0·8	0·05	0·475	–49	0·64	0·46
25. 'Limburgite' (Jensen), Mt. Erebus	B. & W.	87	11·7	57·5	26·4	4·6	0·19	0·75	0·34	0·03	0·46	–31·4	0·73	0·46
28. Olivine-basalt, Hut Pt. Pen.	G.T.P.	86	18	50	23	9	0·26	0·57	0·75	0·04	0·46	–50	0·63	0·46

* Abbreviations of analysts' names:—

B. & W.	= Burrows and Walkom.	H.	= Hogarth.
D.I.B.	= D. I. Bothwell.	J.D.E.	= J. D. Easton.
G.T.P.	= G. T. Prior	N.E.B.	= N. E. Butcher.

Plotting the analyses on this Si°–Az° diagram shows that apart from the first five analyses in Table XII all the analyses can be regarded as belonging to a single series.

The sanidinite from the agglomerate at Cape Adare, the analysis of the 'trachyte' described by Edgeworth David and others, and the two analyses of the 'Mount Cis' phonolitic trachyte are rather widely separated from the rest. The peculiar composition of these Mount Cis rocks with their xenoliths of partly digested sediments has been commented on earlier (this volume, p. 25 and p. 93). The analysis of the sodalite-trachyte (38), which is also from the agglomerate at Cape Adare, also has slightly high Si° and Az° relative to the main body of the volcanics.

Otherwise only two other analyses lie a little apart owing to their slightly high Si°. These are a 'Kulaitic basalt' (22) described by Jensen, and Prior's type 'leucite-kenyte' (16).

Apart from this slight divergence nothing new has been observed to indicate that any real significance should be attached to the author's suggestion that the lavas of Mount Erebus itself do not fall in the same differentiation series as the "Hut Point Peninsula–Cape Bird lavas" (this vol., p. 93). It appears rather that the Ross Archipelago lavas and the Cape Adare lavas can be treated together as one series.

The Si°–Az° diagram brings out another point that may be of interest. Burri in his study of the petrochemistry of the Cape Verde Islands was led to distinguish: a series (III) of extremely undersaturated and often melilite-bearing rocks; a series (II) of feldspathoid-rich rocks; and two series (Ia and Ib) of basaltic-trachytic and basaltic-phonolitic rocks. The Si°–Az° diagram for the South Victoria Land volcanics shows a distribution of points comparable with the series Ib, basaltic-phonolitic series, of the Cape Verde Islands. Following up this suggestion by plotting the Niggli values for this series on the variation diagram for the Ross Archipelago volcanics (this vol., fig. 5) one finds a good general agreement between the two. The agreement is better than that between the variation diagrams for the Ross Archipelago and the Tristan da Cunha volcanics plotted by Burri and Niggli as a representative of an assemblage of Atlantic type, which as previously remarked (this volume No. 1, p. 93) show a general similarity.

Rocks of these different series which have similar Niggli values have not been found, on examination of their thin sections, to resemble each other closely in mineral composition and texture but, in spite of that, the above comparisons as regards the petrochemistry do add to the evidence that the South Victoria Land volcanics belong to the 'Atlantic type'. It would be very interesting to make similar comparisons with volcanic rocks from Mount Kenya and Mount Kilimanjaro in particular and from the Rift Valley in general whenever sufficient analyses of rocks from these areas are available.

II. THOLEIITES FROM THE PRIESTLEY GLACIER, TERRA NOVA BAY REGION

Among the erratics collected by Priestley from the outer moraines of the Priestley Glacier are some fine-grained greyish olive to brownish drab rocks with abundant amygdules or vesicles filled with white zeolites.

These rocks look so much like old volcanic rocks that they were not described along with the hypabyssal rocks of the Terra Nova Bay region although, as will appear, they are very closely akin to the quartz-dolerites many erratics of which occur also in the Priestley Glacier outer moraine.⁽¹⁾

So far as this author is aware 'vesicular' rocks similar to these have not been recorded elsewhere in South Victoria Land by any of the later Antarctic expeditions. It seems worth while therefore to describe Priestley's specimens in some detail.

A. Vesicular fine-grained to medium grained basalts related to the quartz-dolerites.

Nos. 1620, 1831, 1710, 1785, 1945=B.M. 1953, 89 (18, 19, 20 and 21, 40 and 41).

A group of these erratics very similar in texture to quartz-dolerites but containing many irregular druses or small vesicles and a few amygdules filled with zeolites. They are light greyish olive to hair brown in colour, medium-grained, and aphyric. They consist of stout laths of plagioclase, laths of colourless pyroxene, a few small magnetite cubes, and much interstitial dark mesostasis. The pyroxene occurs as plates between or partly enclosing the feldspar, so that the texture is partly micro-ophitic (pl. 1, fig. 1).

The plagioclase is labradorite. The laths show albite and Carlsbad twinning and maximum symmetrical extinction angles measured on the universal stage indicate compositions ranging from $An_{63\text{-}70}$. The pyroxene, nearly colourless in thin section, has 2V 50° to 60°, and $c{:}\gamma$ 43°–45°.

The interstitial mesostasis in 1710 is very dark, frequently opaque, but translucent where the section is very thin and it can then be seen to be turbid glass with swarms of globulites, short black rods, and very slender colourless feldspars. The two other specimens of this group (1620, 1831) have interstitial glass transparent and faintly buff coloured in 1620 and ochraceous buff to ochraceous tawny in 1831.

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(1) Smith (W. Campbell). 'The plutonic and hypabyssal rocks of South Victoria Land'. Brit. Ant. ("Terra Nova"). Exp. 1910. Nat. Hist. Rep. Geology, Vol. 1, No. 6, 1924, p. 214, and map, fig. 1, in vol. 1, No. 5b, p. 146.

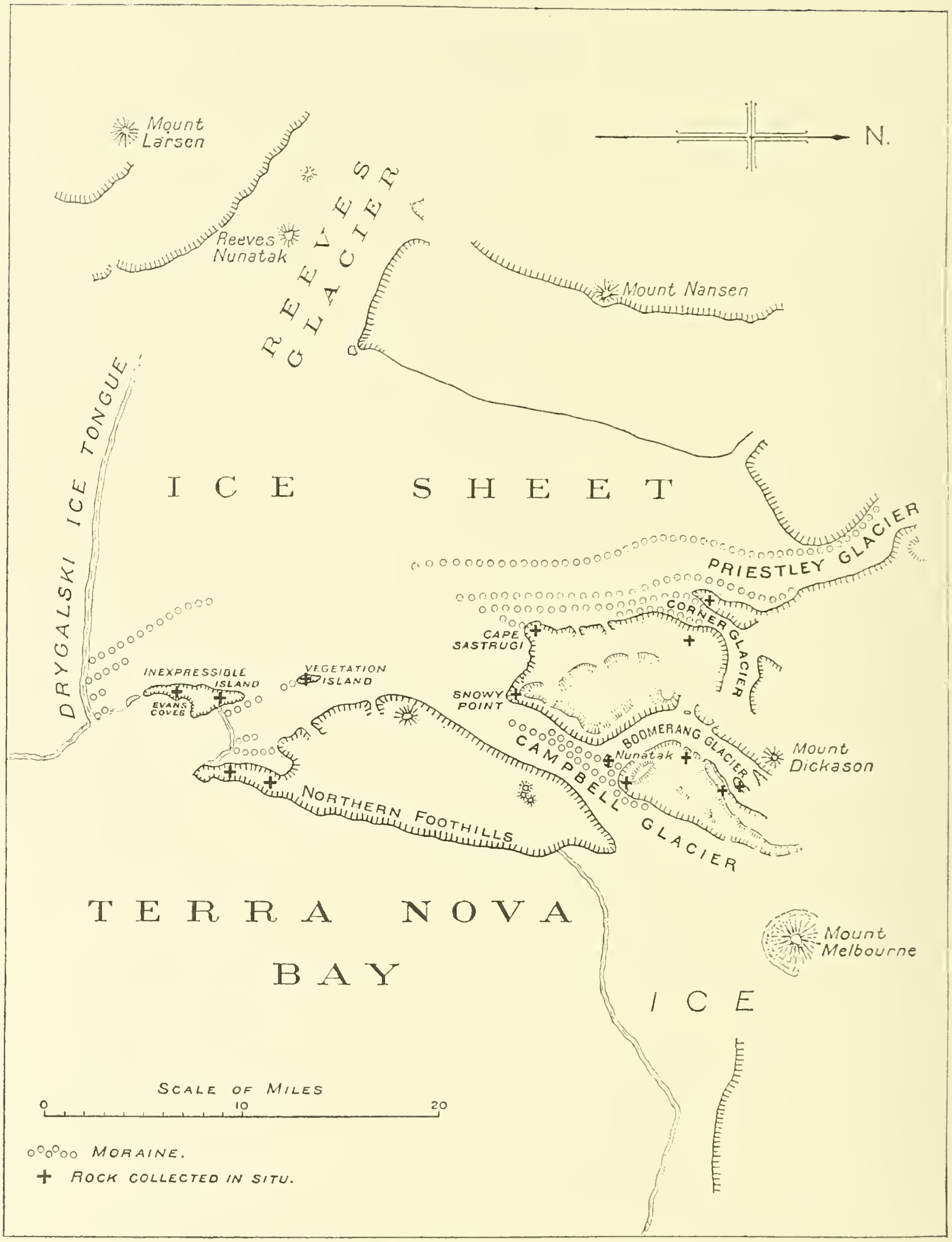

Fig. 1. Map of Terra Nova Bay Region.

A remarkably fresh and compact specimen (1945) is probably related to these. It is olivaceous black to iron-grey in colour. Its texture is ophitic and the mesostasis, which occurs in numerous small patches, is a cinnamon-buff glass with abundant hair-like crystallites.

Other related but finer grained, compact, specimens (1711, 1807, 1895, 1896), several with a very thin platy fracture, have the dark mesostasis gathered in numerous irregular patches occasionally up to 7 mm. across. This mesostasis has crystallized out yielding abundant slender curved feldspars and fern-like skeletal growths of magnetite in a cryptocrystalline perhaps partly quartzose base. Within the patches of mesostasis there are often also slender skeletal plagioclase laths and very long slender augite prisms (1896).

B. In contrast to this group with very few vesicles and a close approach to dolerite in texture there are several specimens of a fine-grained aphanitic basalt, greyish olive in colour which show numerous large vesicles filled by white zeolites and in one case as much as 7 cm. in length. [Nos. 1254, 1798, 1831, 1830]. In thin section these rocks are seen to consist of laths of plagioclase, augite, and some coloured interstitial mesostasis. The feldspar laths form a mesh or framework within which lie platy crystals and grains of pyroxene. There are numerous small, rounded vesicles in addition to the large ones so conspicuous in the hand-specimens (pl. 1, fig. 3).

The plagioclase shows albite and Carlsbad twins with symmetrical extinction angles of 30° to 35° indicating labradorite about $An_{57\text{-}63}$. The pyroxene is augite with moderate 2V and $c{:}\gamma$ 39°. In one specimen [1830] augite occurs as microinsets as well as in the groundmass. The mesostasis, vinaceous fawn to russet vinaceous in colour gives weak aggregate polarisation and contains inclusions of small rods or lines of cubes of magnetite (?). Presumably this is devitrified glass. The fieldspars in these specimens are partly replaced by zeolites.

C. Closely resembling this group in mineral composition and texture are specimens of fine-grained basalts with numerous sub-rounded vesicles and amygdules partly filled with zeolites. The colour of this group is dark vinaceous drab to deep brownish drab. The plagioclase and augite are similar to those in the group just described, but in some of the specimens the feldspars are partly replaced by a colourless isotropic zeolite, probably analcime (?). Small amounts of fine-grained magnetite (?) occur usually near the margins of the area of mesostasis. The mesostasis varies much in amount from one specimen to another. It is pale brown in colour, is weakly birefringent, and contains opaque granules and crystallites, and occasionally also very long, slender feldspars. The feldspars and pyroxene seem to be similar to those in the paler coloured vesicular basalts described above. Extinction angles in the plagioclase laths indicate labradorite near An_{63}. The augite has 2V about 52° and $c{:}\gamma$ 43°. It occurs in prismatic (columnar) crystals rather than as plates and grains and though frequently penetrated by feldspar laths, the two minerals are fairly evenly distributed and both are immersed in, or wrapped around by, the coloured mesostasis. Specimen No. 1817 is similar to this.

Another example [1783] is a fine-grained aphyric basalt, iron-grey to olivaceous black in colour and has frequent roughly spherical vesicles of which the majority appear to be empty, while some very small 'druses' are filled by green chloritic material. The thin section shows a few small insets of a colourless pyroxene and some micro-insets of plagioclase. The pyroxene is enstatite with optic axial angle near 90°, indicating about 20% $FeSiO_3$. The plagioclase of some of the micro-insets is bytownite near An_{85}, but the feldspar laths of the groundmass are labradorite-bytownite with a range from An_{63} to An_{75} to judge from extinction angles measured on the universal stage.

In this rock the plagioclase laths are very sharply defined. They penetrate and are partly enclosed by the colourless augite crystals of the groundmass. Interstices are filled by dark 'glass' which, in very thin section, has a brownish drab colour and is crowded with minute opaque globules and a few black rod-like bodies. Very noticeable in the section of this specimen are circular areas filled with black 'glass' like that of the interstitial mesostasis and in these have crystallized slender, sometimes curved, laths of feldspar, and similarly slender and skeletal, augite prisms. Small vesicles within these spherical bodies are filled by pale green chlorite. A typical example of one of these spherical mesostasis-filled vesicles measures 1·5 mm. in diameter. (Pl. 1, fig. 4). Other examples filled by a lighter coloured mesostasis occur also in No. 1823. Similar mesostasis-filled amygdules have been described from the tholeiite of the Coley Hill dike, nr. Newcastle, Northumberland.⁽¹⁾

Another specimen to be mentioned is a fine-grained, deep greyish-olive basalt with some very small 'druses' filled by white zeolitic material but not otherwise vesicular. Green material resembling celadonite coats one part of the specimen [1836].

There are rare micro-insets of plagioclase and a few small insets of pyroxene. The pyroxene insets are of two kinds. Many are augite, with $c{:}\gamma$ 41° and 2V 70° to 75°; the others, less frequent, are nearly uniaxial pigeonite. Both pyroxenes are colourless in thin section. The texture of the groundmass is intersertal (pl. 1, fig. 2). It consists of small laths of labradorite (about An_{63}), granular pyroxene, frequent very small grains of magnetite (?) and a mesostasis of birefringent material, which may be cryptocrystalline quartz-feldspar aggregate. Its

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⁽¹⁾ Holmes (A.), and Harwood (H. F.). The tholeiite dikes of the North of England. Min. Mag., 1929. Vol. 22, pl. 2, fig. 4, and p. 31.

effective refractive index is below that of canada balsam. Occasionally the mesostasis shows traces of radial structure. The augite grains in the groundmass are slightly altered and darkened at their edges, and there is also present some green chloritic material which occasionally invades the larger feldspar laths.

D. Specimens of greyish olive aphanitic basalt [1454, 1618A, 1947, 1972], some of which have a glassy, tachylytic, selvage along one face, probably represent a marginal facies of rocks like those described above [1254, 1798, 1830, etc.] (p. 169). They have elongated, irregularly shaped vesicles filled with fibrous zeolites.

Under the microscope it is seen that there are frequent micro-insets of labradorite and rare, colourless micro-insets of an orthorhombic pyroxene. This is enstatite with 2V very near 90°. The whole of the groundmass is microspherulitic. In very thin parts of the sections it can be seen that many of the spherulitic growths have formed about a skeletal prism of clino-pyroxene, and that from this radiate fine fibres and beautiful feathery growths of feldspar. The fibres in the spherulites are extremely slender and the general effect in thin section is to give a prevailing turbid brownish colour to the groundmass.⁽¹⁾

All the rocks here described are more or less vesicular. In several specimens the vesicles are up to 7 cm. in length and filled by fibrous zeolites in others they are smaller, rounded and only partially filled. In most cases there are very narrow linings of a chlorite-like mineral, and in some specimens green material of this kind completely fills small vesicles or druses. Preliminary identifications of the zeolites occupying the vesicles in these rocks were made by Mr. M. J. Canham while working in the Department of Mineralogy as a vacation student in the summer of 1960.

The rather large, conspicuous, vesicles described above in one group of these rocks (p. 169) are filled mainly by stilbite, which occurs in long prismatic groups sometimes completely filling the rather flattened vesicles. The dominant zeolite in the smaller, rounded vesicles in No. 1830 is heulandite,⁽²⁾ associated with analcime and very finely fibrous natrolite or thomsonite:

Little vesicles in the rather fine-grained tholeiites in the first group described (p. 167) are sometimes completely filled by single plates of stilbite and others have a fibrous zeolite, thomsonite or scolecite, in a matrix of analcime. Occasionally the centre is filled by quartz.

Small vesicles in the brownish drab tholeiites (p. 169) are occupied by stilbite associated with some heulandite, and the same two zeolites are found in the

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⁽¹⁾ This structure resembles those described in some spherulitic tachylytes, e.g. in some of the tholeiites of Mull. Mem. Geol. Survey Scotland, 1924, Tertiary . . . geology of Mull . . . p. 285.

⁽²⁾ Heulandite in No. 1830 was confirmed by X-ray powder photograph (X. 8968).

vesicles of the greyish-olive microspherulitic specimens (D. p. 171). In this last group apophyllite also is present, and is readily recognized by the pearly cleavage surfaces displayed. It is associated also with fibrous natrolite.

The above description shows that these fine-grained vesicular rocks have much in common as regards both mineral composition and texture. It seems probable that they are closely related to one another and are probably all derived from the same rock formation.

Petrographically they are similar to tholeiites. Comparison with thin sections of typical tholeiites from well known localities confirms this. For instance there is a striking resemblance between the fine-grained, greyish-olive 'basalt' 1836] (p. 170) and a specimen of tholeiite from the Acklington dike at Debdon near Rothbury, Northumberland. A further point of resemblance with the tholeiites of the north of England is the presence in the fine-grained 'basalt' [1783] of spherical vesicles filled with the dark mesostasis described above (p. 170). Precisely similar spherical vesicles were described from the Tynemouth dike by Sir J. J. H. Teall in 1889,⁽¹⁾, and, more recently, they have been recorded and figured by Holmes and Harwood in the Coley Hill dike, a tholeiite of Acklington type.⁽²⁾ Teall noted the spherical form and also the fact that the plagioclase laths lie tangentially to the surface of the spheres and he gave the explanation of these structures. They are bubbles formed after the crystallization of the insets and feldspar laths and before the consolidation of the groundmass. The mesostasis oozed into some of the bubbles completely filling some and partially filling others. In the Antarctic counterpart [1783] some of the bubbles contain no mesostasis. These are lined with chlorite but may be otherwise empty.

Another point that calls for special remark is the identification of small insets of pigeonite together with insets of augite in specimen 1836, and of small insets of orthopyroxene near enstatite in specimens 1783 and 1785 and in the microspherulitic 'basalts' (D. p. 171).

The early formation of enstatite or hypersthene in tholeiites is well known. Holmes and Harwood (op. cit. p. 29 and p. 31) have recorded it as 'rare stumpy prisms' in the Acklington dike referred to above, and the Coley Hill dike is a similar type. On the other hand the presence of insets of pigeonite in effusive rocks is exceptionally rare as noted by Hess.⁽³⁾ H. Kuno⁽⁴⁾ described it as insets in the pyroxene-andesites of the Hakone volcano, Honshu, Japan, where its pre-

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(1) Teall (J. J. H.). On the amygdaloids of the Tynemouth dyke. Geol. Mag., 1889, dec. 3, Vol. 6, pp. 481–3, pl. 14.

(2) Holmes (A.) and Harwood (H. F.). Min. Mag., 1929, Vol. 22, p. 31 and pl. 2, fig. 4.

(3) Hess (H. H.). Pyroxenes of common mafic magmas. Amer. Min., 1941, Vol. 26, p. 533.

(4) Kuno (H.). Preliminary note on the occurrence of pigeonite as phenocrysts in some pyroxene-andesites from Hakone volcano. Journ. Geol. Soc. Japan (Tokyo), 1935, Vol. 42, pp. 39–44.

sence has been explained by supposing that the pigeonite began to crystallize in depth and the magma containing it was suddenly extruded.(1)

In Mull A. L. Hallimond recorded uniaxial augite (pigeonite) as rounded insets in an inninmorite intrusive sheet at Pennygael(2). Also under the name of enstatite-augite it is recorded in Mull(3) as small rounded insets in craignurite, and in the form of pseudomorphs in rocks ranging from granophyre to quartz-dolerite, but all these are intrusive rocks. It seems most likely that our erratic [1836] containing pigeonite is itself an intrusive rock.

The same conclusion as to their probable intrusive character, may be drawn from the petrography of many of the other rocks here described as tholeiites. All the tholeiites of the north of England described by Holmes and Harwood are dike-rocks, and the tholeiites of Mull and Ardnamuchan are either cone-sheets or dikes. Most of the European tholeiites are intrusive rocks.

It seems very likely then that except perhaps for the most highly vesicular examples these tholeiite erratics are derived from small intrusions and not from lava flows. As such they will represent a fine-grained variation of the quartz-dolerites and these in turn presumably belong to the great dolerite sills intruding the Beacon Sandstone which is abundantly represented among the erratics of the Priestley Glacier. The highly vesicular specimens may indeed be derived from effusive rocks and if so they are the only evidence of a volcanic phase of the Ferrar Dolerite(4) so far recorded.

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(1) Hess (H. H.), op. cit. supra, p. 581.

(2) Hallimond (A. L.). Optically uniaxial augite from Mull. Min. Mag., 1914, Vol. 17, p. 97.

(3) Bailey (E. B.) and others. Tertiary and Post-Tertiary Geology of Mull . . . Mem. Geol. Surv. Scotland, 1924.

(4) Harrington (H. J.). Nomenclature of rock units in the Ross Sea Region, Antarctica. Nature, 1958, Vol. 182, p. 290.

III. VOLCANIC ROCKS FOUND AS ERRATICS IN THE TERRA NOVA BAY REGION

Several small erratics of volcanic rocks were found by Priestley in the moraines of the Boomerang and Campbell Glaciers. Some were collected at Camp 7 on 19th Jan. 1912, a few at the nunatak at the entrance of the Boomerang Glacier, and a few more further out near Inexpressible Island (*see* map, fig. 1). The Campbell Glacier commences 'on the neck between Mount Dickason and Mount Melbourne'⁽¹⁾ Priestley found a granite ridge covered with erratics among which olivine-basalt was very common, and a nunatak up the glacier was found to consist 'of red and black basalt, being quite clearly the southernmost outlier in this region of the volcanic series' [of Mount Melbourne].

The Boomerang Glacier is a tributary of the Campbell Glacier coming in on its westward side with walls of granite and schist but in its upper course it bends north-east and is probably fed by ice which comes from between Mount Dickason and Mount Melbourne as in the case of the Campbell Glacier (op. cit. p. 61).

Distant observations by Ferrar and others have indicated that Mount Melbourne consists of volcanic rocks⁽²⁾ but it has never been reached. Specimens collected on the Southern Cross Expedition labelled 'Newnes Land' were thought to have come from Mount Melbourne, presumably coastal cliffs, but the specimens arrived in London unlabelled and their localities were only guessed at by Lieutenant Colbeck and L. Bernacchi by comparisons with their own specimens and from memory. Such material cannot be regarded as trustworthy samples. The erratics from the Boomerang-Campbell moraines collected by Priestley thus provide the first reliable samples of the rocks of the Mount Melbourne volcanic centre.

Seven of the erratics collected are basalts. One (1496), hematite-red in colour, is fine-grained, and slightly scoriaceous and contains some inclusions consisting of granular quartz. These resemble fragments of Beacon Sandstone. A fresher example probably of the same kind of basalt is from the nunatak at the entrance of Boomerang Glacier (1500 J). This is a very fine-grained, slightly vesicular black basalt. It has abundant micro-insets of plagioclase, olivine, and augite in a black, extremely fine-grained base of feldspar microliths, grains of magnetite, and pyroxene and some doubtful interstitial glass.

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(1) Priestley (R. E.). Physiography (Robertson Bay and Terra Nova Bay Regions). Brit. (Terra Nova) Ant. Exp. 1910–1913, 1923, p. 59.

(2) See this volume, footnote, p. 111.

Similar to this but with the insets of plagioclase, augite and olivine all better developed is 1357 T. The plagioclase is labradorite near An_{62}. [The augite, very pale buff, has 2V near 60°]. The groundmass is extremely fine-grained and very dense. A small inclusion seen in the thin section of this basalt consists of granular quartz.

Two of the basalts contain insets of olivine up to 1 cm. across in a fine-grained base iron-grey in the hand-specimen. This groundmass consists of abundant laths of labradorite, augite and small cubes of magnetite with an interstitial colourless base. In one of the specimens (1304) this is crowded with minute rods of ilmenite or magnetite, but in the other (1503) some of it appears to be alkali-feldspar containing minute flakes (biotite ?) and needles of apatite (?).

The remaining two basalts (1499, 1502) are similar in the hand-specimen to the last described (1503) but, in addition to the large olivine insets, they have large black insets of augite as well. The groundmass is very fine-grained and iron-grey in colour. It consists of abundant laths of labradorite (An_{55}), crystals of augite and cubes of magnetite (?) and occasional olivines, with small amounts of a colourless base. This colourless base contains abundant little hair-like and rod-like crystallites arranged in parallel groups like skeletal crystals.

These basalts with insets of augite and olivine resemble tolerably well type C from Cape Adare (p. 118) except that brown hornblende is not found in the erratics from the Boomerang–Campbell moraines. The three basalts with insets or micro-insets of plagioclase, augite, and olivine are less confidently compared with the black glassy olivine-basalts, type A (p. 115). These two varieties of basalt, as has been shown in an earlier chapter (p. 151), are very similar in composition though slightly different in the habit and distribution of the minerals. It must be noted also that basalts like the Cape Adare, type C, with augite and olivine insets are represented among erratics on the plateau above the Cape (p. 138). Also one of the second group (1496) matches tolerably well some pebbles from Ridley Beach (343 and 430), and one erratic from the Newnes Glacier (GN 962).

The middle group (1304, 1503) with insets of olivine up to 1 cm. across find no exact match among the Cape Adare specimens, but there are similar basalts in the Hut Point Peninsula, e.g. D25H and D20H from Harbour Heights (p. 77), and also among the basalts from the recent craters on the mainland in the Ferrar Glacier region (D2F, p. 89).

One of the basalts with large augites and olivine (1500) also can be matched by specimens from these recent craters (D13K and D16F).

It is interesting also to note that inclusions of sandstone and of dolerite were detected in the basalts of Cheyenne Crater and from the lava flow on the opposite side of the Taylor Valley as they are in some of the erratics from the Boomerang–Campbell moraine.

One of the basalts of the Boomerang–Campbell moraine (Camp 7, 19/1/12) is a trachybasalt, perhaps comparable to mugearite (1511). It is fine-grained, aphanitic, and slate-olive in colour. This contains some micro-insets of plagioclase and augite, and small magnetites in a very fine-grained groundmass of short laths of oligoclase (An_{25}), small magnetites, many bright, colourless, little crystals of olivine and augite, abundant small cubes of magnetite and a colourless interstitial base of alkali-feldspar.

There is one other specimen like this among the erratics from the Priestley Glacier.

Similar rocks are found among the pebbles on Ridley Beach (332, 333). One of these is described (p. 139) as 'either trachybasalt or tephrite'. It has a better developed trachytic texture. Another rather similar pebble but definitely more basic was described as an aphanitic basalt 'perhaps near to the trachybasalts' (372, p. 139).

Some of the basalt erratics described above (1304, 1503) were compared with basalts from Hut Point Peninsula.

Another close similarity between specimens from the Hut Point Peninsula and erratics from the Boomerang-Campbell moraines is found in a specimen of basalt-tuff (1290, 1334). This is very similar to a tuff from 'Boulder Cones' (D28H), p. 15. Similar tuffs were also found by Priestley in the moraines of the Murray Glacier and have been fully described (p. 145). The specimen from the Boomerang–Campbell moraine contain precisely similar lapilli of yellow-glass and basalt lapilli with a very fine-grained groundmass but they do not contain the variety of lapilli found in the Murray Glacier tuffs. The glassy lapilli consist of buff yellow to maize-yellow glass crowded with small spherical vesicles, and also spheres of slightly darker yellow 'glass' showing a black cross between crossed nicols. In addition there are frequent crystals of plagioclase and of colourless olivine. Some of the spherical vesicles contain tufts of a colourless mineral with positive elongation and refractive index less than balsam, probably a zeolite.

Besides the erratics of olivine-basalts Priestley found a few of alkali-trachytes. One of these (1500 H) was collected at the nunatak at the entrance to the Boomerang Glacier. The others were found among erratics on Inexpressible Island.

The specimen from the nunatak is a rounded pebble, deep olive-grey on a freshly broken surface, and very slightly vesicular. It consists of small laths and plates of alkali-feldspar with frequent small grains and prisms of pale green pyroxene and very small magnetites. Some of the pyroxene is interstitial to the feldspar laths, but there is also some rather turbid interstitial material and some which is colourless and isotropic and so may be sodalite. The only micro-insets are of a greenish-grey pyroxene as crystals, 0·05 mm., across and somewhat larger crystals of nearly colourless olivine and of magnetite. These average 0·18 mm. in diameter.

The other alkali-trachytes, from Inexpressible Island, came no doubt down the Campbell or Boomerang Glacier. They are very small fragments, tea-green in colour and showing on the broken surfaces glistening feldspar cleavage faces. In thin section they are seen to have a fine-grained groundmass consisting mainly of slender laths of alkali-feldspar, like that of the specimen just described, but they have also frequent insets of alkali-feldspar, and micro-insets of a green pyroxene and of magnetite. No olivine micro-insets were seen. The pyroxene is pleochroic from deep grape-green to honey-yellow. The feldspar insets are simple Carlsbad twins and have extinction angles of 10° to 15°.

Alkali-trachytes rather similar to these are known among the pebbles on Ridley Beach (668, 579, 584, p. 135), and they occur also as erratics on the plateau on the top of Cape Adare (p. 136) and as boulders in the agglomerate in the face of the cliff at the north end of the Cape (p. 129).

The erratics on the plateau may have been carried by ice from the Mount Melbourne–Mount Dickason volcanic centres (*see* Priestley, op. cit. 1923, p. 10), and the pebbles on Ridley Beach may be derived either from erratics fallen from the plateau, or from material carried up the coast from further south, but the alkali-trachyte boulders in the agglomerate cannot be accounted for in either of these ways. Either they must be erratics like the 'quartzite' and dolerite and other igneous rocks described by Priestley, or they must be volcanic rocks thrown up or brought into the agglomerate of a volcanic vent, as the sanidinite 'bombs' must have been (this volume, p. 135). In either case they would be among the earliest volcanic rocks of the Cape Adare centre. (Priestley, op. cit. 1923, p. 11).

No volcanic rocks of this kind were found associated with basalts of Hut Point Peninsula, but somewhat similar rocks are recorded from the neighbourhood of Mount Terror and Cape Crozier, and on the Dellbridge Islands in the McMurdo Sound Region as well as from a debris heap on Minna Bluff (p. 147).

That they are available at some places down the coast between Cape Adare and Newnes Bay is indicated by the presence of phonolitic trachytes and trachytoid phonolites in material dredged off Cape Adare and west of Coulman Island (p. 147), and Lieutenant Colbeck on the Southern Cross Expedition found a fragment of alkali-trachyte or phonolitic trachyte on an ice-floe in Wood Bay.(1)

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(1) Prior (G. T.), Report on the rock-specimens collected by the 'Southern Cross' Antarctic Expedition. *In* Report on the collections of Natural History made in the Antarctic Regions . . . London, 1903, p. 330.

It is more fine-grained than any of the Ridley Beach alkali-trachyte pebbles examined, but clearly related to them.

An erratic of kenyte (1312) found at Evans Coves is of considerable interest.

Numerous erratics of this readily recognizable porphyritic lava were recorded by Edgeworth David and Priestley during the Shackleton Expedition on Cape Roberts south of the entrance of Granite Harbour at about 20 to 30 feet above sea-level. Their presence there was attributed to transport by floating ice from Ross Island(1).

Priestley found two kenyte boulders on the raised beach at Evans Coves of which the specimen now described is one. It measures 20 × 14 × 6 cm., is roughly elliptical in outline, and one side is discoloured as if it had lain in one position for a long time. The other specimen was the size of a man's head. The two blocks of kenyte lay, the one at 80 and the other about 50 feet above sea-level. At this level local erratics were almost wanting. Also nothing approaching kenyte in composition or appearance was seen amongst the erratics found on the foothills or on the moraines of the glaciers.(2) Priestley concludes that the two boulders of kenyte 'came from the south in the neighbourhood of McMurdo Sound, probably from one of the spurs of Mount Erebus itself, on a piece of floe ice or a small berg which stranded on the beach before the recent elevation [of the beach] had commenced'. (Priestley, op. cit. 1923, p. 56). This is an important piece of evidence in support of Priestley's opinion that the raised beach at Evans Coves is very recent.

The identification of the boulder (1312) with kenytes described from Ross Island is amply confirmed by the petrographical examination of the specimen.

A cut surface on the specimen shows abundant typical lozenge-shaped insets of 'anorthoclase' up to 2 cm. in cross-section in a black, slightly vesicular, glassy base. The crystals have not weathered out much on the surface. In thin section the glass is near cinnamon buff to pale pinkish buff. In addition to the anorthoclase there are some pyroxene insets accompanied by small magnetites and apatites and occasional small olivine crystals. In all these respects the boulder closely resembles several of the glassy kenytes described from Ross Island.

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(1) David (T. W. E.) and Priestley (R. E.), Brit. Ant. Exp. 1907–9, Geology, vol. 1, 1914, p. 82.

(2) The only other specimen with anorthoclase insets that has been found in the Terra Nova Bay or Cape Adare Region is one collected on the Southern Cross Expedition at Cape Adare [B.M. 85752, 24]. This was described by Prior (op. cit. 1903, p. 329) and re-described on p. 137 of this volume, where it is noted that its feldspars, both in size and habit, are quite unlike those in the Mount Erebus kenytes. Nor are they like the feldspars in the boulder from Evans Coves.

IV. VOLCANIC ROCKS FOUND AS ERRATICS AT GRANITE HARBOUR

Debenham's collection of rocks from Granite Harbour includes four specimens of volcanic rocks. These are erratics, numbered D52G and listed as: 'Lavas, erratic at Granite Harbour'. They are of considerable interest as, apart from some boulders of kenyte reported on Cape Roberts by Edgeworth David and Priestley on the Shackleton Expedition, no volcanic rocks, erratic or in situ, are known in the Granite Harbour district.

One of the specimens (B.M. 1953, 89(65)) is very fine-grained, iron-grey in colour, and riddled with small, glass-lined vesicles 0·5 to 1 mm. in diameter. Very small insets can be seen with a hand-lens. These prove to be olivine, colourless in thin section, idiomorphic, and up to 0·75 mm. in length. They are frequent but not abundant. The groundmass consists of abundant, small prisms of pale buff augite and cubic crystals of magnetite in a turbid, dusky drab glass. The pyroxene prisms average about 0·05 mm. in thickness. The only feldspar is very rare and is seen only as elongated plates of plagioclase of later crystallization than the pyroxene and magnetite.

This rock is a limburgite.

No similar rock has been described from Ross Island or elsewhere in South Victoria Land but a limburgite from Franklin Island described by Prior is a good match. The Franklin Island specimens collected by both the Southern Cross and the Discovery expeditions are, however, not vesicular and they seem to contain rather less magnetite and the glass of the groundmass is lighter coloured. These are trivial distinctions but of course similar limburgite may easily occur in Victoria Land itself.

The rocks described by Jensen as limburgites are not well named and the lava from Fortress Rocks on Hut Point Peninsula described in this volume (p. 78) contains a few thin laths of labradorite so feldspar is more in evidence than in the limburgite now described.

A second specimen [B.M. 1953, 89(64)] is a porphyritic olivine-basalt. It is dark olive-grey in colour, with many near-spherical vesicles up to 5 mm. across. Under the microscope it is seen to consist of colourless insets of olivine up to 3 mm. in length, abundant in a medium-grained groundmass of plagioclase laths and allotriomorphic augite with frequent small magnetites. The plagioclase laths average about 0·03 mm. in thickness. There is only a small proportion of interstitial material. Some of this contains rods and skeletal growths of ilmenite or magnetite and may be glass, but other parts seem to be birefringent.

The two other specimens (1953, 86 (63, 66)) are both of the same kind of rock. They are vesicular, dark olive-grey rocks crowded with insets and groups of insets of black augite and slightly smaller olive-yellow or browner stained olivines. White specks in the medium-grained groundmass are due to small feldspars. In thin section the olivines are colourless and up to 1 mm. in length, the augites pale greyish vinaceous in colour range up to 5 mm. across. Both are idiomorphic. The augite often occurs in groups of several crystals. The groundmass is medium-grained and coarser grained than for most basalts. It consists of laths of plagioclase with granular augite and frequent small magnetites. This augite is unusual for its deep colour, near vinaceous purple. Interstitial material is very small in amount and consists of still finer-grained feldspar, augite and dusty opaque magnetite or ilmenite. In some parts of this interstitial material the little pyroxenes occur as closely packed prisms in parallel position in the birefringent base. The augites and the feldspars of the groundmass average 0·06 mm. in thickness, but there are many feldspars, perhaps to be described as micro-insets, that are up to 0·15 mm. across.

These two erratics must be very near in mineral composition to the rocks described by A. Lacroix from Madagascar as ankaramite but the groundmass of the erratics is coarser in grain-size. The rock described by C. Gagel from Madeira as madeirite is also similar but it also has the finer-grained groundmass. With this proviso on the grain-size of groundmass the two erratics may be described provisionally as ankaramite.(1)

Nothing like these rocks has been described from Ross Island or elsewhere in South Victoria Land. That is, of course, not to say that such rocks do not occur but in view of the records of kenyte erratics that indicate possible centres of vulcanicity on the mainland (p. 196) one must regard a mainland source as also possible for the erratics at Granite Harbour.

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(1) A rather similar rock from S. Vicente, Cape Verde Islands has been described and figured by G. M. Part.

Part (G. M.). Volcanic rocks from the Cape Verde Islands. Bull. Brit. Mus. (Nat. Hist.) Min., 1950, vol. 1, no. 2, p. 60.

V. PEBBLES DREDGED FROM THE SEA-FLOOR IN THE BAY OF WHALES

The Bay of Whales, as it was then called, was visited by the *Terra Nova* in February, 1911. The intention was to land a party under Commander V. L. A. Campbell with the object of exploring King Edward Land. When the ship arrived they found anchored in the 'bay' Roald Amundsen's ship, the *Fram*, and Amundsen preparing to race Scott to the Pole. The plan to make a base near the Bay of Whales had to be abandoned. Sir Raymond Priestley has given an account of this historic meeting and records that after an exchange of visits between the Norwegian and British parties, to quote: "The *Terra Nova* loosed her anchor and we steamed slowly out the bay trawling as we went".(1)

The dredge brought up a surprising quantity of stones along with mud and bottom fauna, and indeed supplied samples of the rocks of the mainland far exceeding in bulk and in variety the rocks collected by Amundsen's party on their journeys on land.

The position of the Bay of Whales is approximately 78° S., 166° W., about 140 miles from Cape Colbeck. In the list of collecting stations it is No. 191 and the depth is given as 194–250 fathoms (355–457 m.) and the date, February 4, 1911.(2)

Priestley examined the pebbles on board and records in his diary, February 5, 1911: "I have 20 or 30 pounds of varied rock material through this haul and it alone was well worth the trouble and the wasted steam". After the expedition returned he made thin sections of many of the pebbles and re-examined them. He regards the material as moraine, glacier borne from King Edward Land, and perhaps from a not very distant source.

A few more specimens have now been sliced and altogether some forty thin sections have been examined out of a total of about three hundred pebbles. These range in size from quite small stones up to small cobbles. The heaviest weighs 530 grams and measures 10 × 8 × 4 cm. However, there are only four approaching these dimensions and the average volume is probably 4–5 cm^3.

Detailed descriptions of the sectioned specimens have been written and these will be filed for future reference. The following report gives a brief account of the kinds of rock represented with fuller descriptions of a few of the more interesting ones.

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(1) Priestley (R. E.). Antarctic Adventure. Scott's Northern Party. 1914, p. 40.

(2) Harmer (S. F.) and Lillie (D. G.). List of collecting stations. Brit. Ant. ("Terra Nova") Exp., 1910. Natural History Reports. Zoology, 1914, vol. 2, p. 7.

Various collections of rocks outcropping above the ice in Marie Byrd Land have now been made by parties operating during Admiral Byrd's Expeditions and later under the U.S.A. Antarctic I.G.Y. Project, 1957–1959.

One account of the petrography of these rocks has already appeared(1) and others are expected in the near future. The rock exposures so far described are all at great distances from the Bay of Whales. The nearest outcrops of which the rocks have been described are Scott's Nunataks (77° 13′ S., 153° 20′ W.) where specimens of granites, granite-pegmatite, amphibolites and fine-grained gneisses were collected by Amundsen's party, and described by J. Schetelig in 1915.(2)

The most prevalent kinds of rock among the pebbles are fine-grained quartzites and quartz-schists with muscovite developed in the matrix between the grains. Many of these are greenish-grey, deep olive-grey to storm grey, in colour and show some slight degree of foliation. This sometimes results in a lenticular disposition of fine-grained material around the larger (0·3 mm.) grains of quartz. Great quantities of smaller quartz grains, with feldspar among them, and abundant small but definite muscovite flakes make up the matrix (102). Others of these greenish-grey quartzites contain a little biotite in addition to muscovite. Occasionally quartz grains are over 1 mm. in diameter, but the average in different specimens ranges from 0·15–0·5 mm.

A few pebbles of a cream-coloured, fine-grained quartz-schist with small flakes of muscovite have patches of calcite developed intermittently along parallel planes (1983).

Rocks of a somewhat lower grade of metamorphism are represented by greenish-grey pebbles showing varying degrees of fissility. One of these (122) consists of very fine-grained quartz with an abundant development of small flakes of green chlorite and perhaps also muscovite. The grain-size of the quartz averages about 0·02 mm. This appears to be a metamorphosed siltstone. The more fissile of this group can be classified as phyllites.

Almost as frequent as the greenish-grey quartzite and quartz-schists are very fine-grained olive-grey to brownish-drab quartzose rocks. Some of these may be quartzites but those examined in thin sections appear to be metamorphosed impure sandstones or siltstones. They are foliated and both biotite and muscovite are developed between the quartz-grains, biotite often being dominant. Quartz-grains are of all sizes up to 1 mm. across though few attain this size (164).

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(1) Anderson (V. H.). The petrography of some rocks from Marie Byrd Land, Antarctica. Ohio State University Research Foundation Report. 825–2–Part 8, 1960.

(2) Schetelig (J.). Report on rock-specimens collected on Roald Amundsen's South Pole Expedition. Videnskaps. Skrifter, Christiania, I.Mat. naturv. Kl., 1915, No. 4.

A rock of this kind, deep slaty brown in colour is a "spotted schist" in a fairly high grade of metamorphism (1984). This consists of a very fine-grained aggregate of biotite with muscovite (?) and some quartz, and occasional grains of sphene and magnetite. In this matrix are many oval patches consisting of a flakey mineral with low birefringence, negative elongation, and straight extinction: perhaps an optically positive chlorite. These are probably pseudomorphs and they resemble in shape the oval patches in a schist (D2K) from the moraines of the Koettlitz Glacier (vol. 1, p. 140). These are thought to be pseudomorphs after andalusite but they consist mainly of muscovite, not chlorite.

There are a few pebbles of fissile biotite-quartz-schists, dark brownish drab in colour; also a few of well foliated biotite-gneiss, one with small garnets in some biotite-rich bands (177). There is also one pebble of a pink hornblendic granite-gneiss with coral-pink feldspars, and with mylonite veins between the quartz and feldspar fragments (142).

Two or three pebbles are quartz-syenites in composition. One of these has very much the appearance and texture of a charnockite. A mineral in this pebble appears to be allotriomorphic corundum. It is colourless in thin section, uniaxial negative, and has rather high birefringence (131).

Remarkably frequent among the pebbles are quartz-feldspar-porphyries with abundant black quartz insets, with smaller insets of white or cream-coloured feldspar (orthoclase?), in an olive-buff to light greyish-olive groundmass. The quartz insets are occasionally as much as 4 mm. across but they average something less than half this. These porphyry pebbles are almost as abundant as the greenish-grey quartzites and quartz-schists: 20 as compared with 25 per cent as estimated on a count of over 300 pebbles.(1) A thin section (167) shows, in addition to the quartz and feldspar insets, small clots of deep greyish-olive biotite in a fine-grained groundmass consisting of rounded crystals of clear quartz in a base of feldspar of low refractive index (orthoclase?).

There are a few pebbles of biotite-feldspar-porphyry with a cryptocrystalline groundmass (175) cream to buff-brown in colour in the hand-specimen.

Related to these quartz-porphyries are several pebbles with an aphanitic groundmass, olivaceous black streaked with iron-grey, and shown on examination of thin sections to be partly glassy and partly devitrified glass (184). The glass is near light brownish-drab in colour, and shows well-marked flow structure. This rock may be described as a porphyritic rhyolite, or perhaps as a rhyolitic-tuff, as much of the quartz and some of the feldspar occurs as broken crystals.

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(1) It was the constant recurrence of this quartz-feldspar-porphyry in the samples that led Priestley to the conclusion that the source of this rock was not far distant.

Another pebble which contains fragments of glass with flow structure like that just described contains also abundant "lapilli" of an opaque vesicular "glass", with angular fragments of quartz, some feldspar and an occasional pyroxene. The hand-specimen, buffy-brown in colour, has the appearance of a detrital rock but the abundance of glassy material seems to indicate that it is probably a tuff. A remarkably constituent, however, is glauconite. This is present only as a few rounded grains. Hitherto it has been recorded in South Victoria Land only from the Beacon Sandstone.(1) This pebble (1982) was the second largest pebble in the dredge. It measures 7×5×4 cm. and weighs 387 gms.

There is evidence in some of the pebbles that the quartz-porphyries just described have, in places, been involved in metamorphism of rather low grade. There are two pebbles which seem to indicate this. One of them (179), shows in thin section idiomorphic and hypidiomorphic quartz and plagioclase, altered orthoclase, and frequent flakes of tawny-olive biotite in a groundmass resembling that of the quartz-porphyries, but with ragged flakes of 'new' biotite enclosing the rounded quartz-grains of the groundmass and there developing sieve structure. The other (141), perhaps in a further stage of metamorphism, shows turbid feldspars with sieve structure and some altered insets of biotite occasionally enclosing epidote while the groundmass though still showing the same fabric as the quartz-porphyries has its feldspar now represented by flakes of muscovite.

This evidence indicates that the quartz-feldspar-porphyries belong to an early period in the history of this part of Antarctica probably earlier than the Beacon Sandstone and perhaps as old as the more recent members of the Ross System in South Victoria Land (i.e. Lower Palaeozoic).

Volcanic rocks such as might be similar in age to the volcanic rocks of Ross Island and Cape Adare are very scarce in the dredged specimens: only seven pebbles were found among over three hundred examined. One of these is an olivine-free andesine-basalt (100); one may be mugearite (140); and a third (133) is a hornblendic 'trachyte' with insets of sanidine and plagioclase, and occasional dark brown hornblendes. It somewhat resembles some of trachytoid phonolites of Inaccessible Island or of Great Razorback but contains less of the dark minerals and none of the pyroxene insets that occur in these rocks (this volume, pp. 28 and 29).

The rock (100) provisionally named andesine-basalt has micro-insets of augite and andesine in a turbid, brownish-black glassy groundmass crowded with laths of plagioclase with low extinction angles indicating oligoclase-andesine.

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(1) Stewart (D.). The petrography of the Beacon Sandstone of South Victoria Land. Amer. Min. 1934. Vol. 19. p. 353.

Pebbles of sedimentary rocks are almost as scarce in the dredge as the volcanic rocks. They are fine-grained compact sandstones. A few are buff coloured on broken surfaces but the majority are white and contain occasional pebbles of white vein-quartz (178). These resemble the Beacon Sandstone.

One pebble of sandstone with a dark purple-drab sandy matrix contains abundant angular fragments of a greenish-grey quartzite (?). Only one pebble of this kind was seen (197).

The only other sedimentary 'rocks' represented appear to be of relatively recent formation. These are pebbles of consolidated calcareous mud often containing aggregates of small, highly polished pebbles in a crystalline calcite cement. Many of the pebbles are similar to some of the slightly metamorphosed dark, fine-grained, quartzose rocks so frequent among the pebbles of the dredge. Dr. J. D. H. Wiseman, who kindly examined the calcareous mud, found no benthonic or planktonic organisms present apart from rare minute sponge-spicules. The carbonate material in the mud is extremely fine-grained. In these respects it resembles the "clay" mentioned by Debenham as having been obtained in one haul off the edge of the Barrier and described as pieces of hard clay interspersed with grit and small pebbles. (Vol. 1, no. 3, p. 99). Indeed Debenham may be here describing the actual specimens from the Bay of Whales. He regards it as 'Boulder Clay' formed from the fine-grained material carried in the base of the glaciers.

VI. SUMMARY OF THE REPORTS ON THE GEOLOGY OF SOUTH VICTORIA LAND

So many years have elapsed since the first reports on the geological results of the Terra Nova Expedition were published that it seems worth while, in this concluding report, to present a summary of the whole series.

When the Terra Nova Expedition sailed in 1910 the main geological formations, their apparent succession, and some idea of the structure of South Victoria Land had been established as a result mainly of the two earlier expeditions of Scott in the *Discovery*, 1901–4, and of Shackleton in the *Nimrod*, 1907–9.

The story of the geological exploration of South Victoria Land actually begins with the voyages of Sir James Clark Ross, who sighted the mainland of South Victoria Land in 1841 and observed the two volcanic peaks on Ross Island and named them, after his two ships, Mounts Erebus and Terror. Mt. Erebus was active at the time of this discovery.

The surgeon in *Erebus*, [Sir] Robert McCormick was also one of the two naturalists on Ross's expedition, and he recorded the rock-specimens collected from the islands on which landings were made, from dredges, and, more unusual, from the stomachs of seals and penguins which he dissected.

McCormick noted that many of these pebbles were of 'granite', and a block of grey granite was dredged up in over 270 fathoms in lat. 72° 31′ S., long. 173° 39′ E., on 19th January, 1841. This, as Ross realized, had probably been carried by an iceberg and indicated the proximity of a continental land-mass.

The collection of pebbles from the penguins' and seals' stomachs were not further examined by any geologist until G. T. Prior described them in 1898, listing them as: granite, epidiorite, basalt, rhyolite and rhyolite-breccia, and a micaceous quartz-grit. This additional information was, of course, of interest but by 1898 the first man had landed on the Antarctic Continent and sampled the rocks for himself.

The Norwegian whaler *Antarctic*, Captain Lars Kristensen, had reached Cape Adare in 1894. Carstens Borchgrevink, one of the crew, had landed with others and collected a few fragments of rocks and pebbles. These were described by T. W. Edgeworth David, W. F. Smeeth and J. A. Schofield in 1896. Borchgrevink returned to Cape Adare in the *Southern Cross* and wintered there, 1898–9, and the rocks collected on this expedition were described by G. T. Prior who recorded volcanic rocks, mostly basalts, and also pale green slates and quartz-grits.

Twentieth century exploration of South Victoria Land opened with the Discovery Expedition of 1901–4, led by Captain Robert Falcon Scott, accompanied by [Sir] Ernest Shackleton, with Dr. E. A. Wilson as doctor and naturalist and H. T. Ferrar as geologist. This expedition and the two that followed it were based on Ross Island in McMurdo Sound. Ferrar collected volcanic rocks from Mount Erebus and other parts of Ross Island, and on the mainland he established the existence of metamorphic rocks including crystalline limestones, of two distinct granites, and of a very extensive sandstone formation named from Beacon Heights in the Ferrar Glacier region, the Beacon Sandstone. He described great sills of quartz-dolerites, the Ferrar Dolerites as they are now called, penetrating the sandstone, and he also discovered in the sandstone thin carbonaceous bands in which he sought without success to find recognizable plant remains.

The report on Ferrar's collection of rocks was written by G. T. Prior. He gave a description of the quartz-dolerites, of the Beacon Sandstone and of the plutonic and volcanic rocks. Prior showed that the remarkable lavas of Mount Erebus with large crystals of feldspar were similar to rocks from Kilimanjaro, named 'Rhombenporphyr' by Finckh, and to the lavas from Mt. Kenya to which J. W. Gregory had given the name 'Kenyte'.

In reporting on the volcanic rocks of Cape Adare in 1902 Prior had pointed out their general resemblance to the East African volcanics which by that date had become known from collections made by J. W. Gregory and Sir Harry Johnston in British East Africa and by the German explorers. His examination of the volcanic rocks of Ross Island added further evidence to support this comparison.

The Discovery Expedition was followed by Shackleton's British Antarctic Expedition in 1907–9 in the *Nimrod*. He took with him as geologists [Sir] T. W. Edgeworth David, Professor of Geology in the University of Sydney, [Sir] Douglas Mawson, and [Sir] Raymond Priestley, then an undergraduate of Bristol. They extended Ferrar's observations, made a successful ascent of Mount Erebus, and carried their exploration along the coast and into the Granite Harbour region north of Ross Island. In their reports published in 1914 they drew the main lines of the structural geology and they showed how the volcanic centres are related to a main north and south fault from Ross Island to Cape Adare. This added still further to the interest of Priors' comparison of the volcanic rocks of South Victoria Land with those of the African Rift Valley. Shackleton's Polar Party on the ascent of the Beardmore Glacier made two discoveries of fossils of very great interest. Near the entrance of the glacier they found among moraine material a dolomitized limestone-breccia containing remains of *Archaeocyathus*, definitely referred to Cambrian in age⁽¹⁾; and at Buckley Island they found coal seams and fossil wood. This was identified by Professor Goddard as possibly a gymnospermous plant indicating perhaps Lower Carboniferous or Upper Devonian age. This established for the first time the existence of an arborescent plant on the Antarctic Continent.

The above is a brief account of the extent to which the geology of South Victoria Land was known when Captain Scott's Expedition in the *Terra Nova* set sail in 1910. Scott had a strong scientific staff with Dr. E. A. Wilson as scientific director, S. C. Wright as physicist, and three geologists, Raymond Priestley who had already served with Shackleton's expedition, Griffith Taylor, and Frank Debenham. The results of their work, apart from important memoirs on Glaciology and on the Physiography of the region, are described in these reports on the Geology. It was originally planned that both Priestley and Debenham would have time and opportunity to work out the results and to report on their collections and with that end in view on the return of the Expedition both went as post-graduate students to Cambridge, working in the Department of Geology there. This excellent arrangement was soon to be upset for within a few months the first World War had broken out and both Priestley and Debenham were in the Army almost at once. However arrangements had been made for specialists to undertake the description of some parts of the collections. Sir Arthur Smith-Woodward, Keeper of Geology in the British Museum (Natural History), had agreed to describe the fish scales and plates discovered by Debenham, and Professor A. C. Seward the fossil plants. Both were acknowledged authorities on their subjects. Professor Seward's report on 'Antarctic Fossil Plants' was the first to be completed and was issued on 24th October, 1914. No further reports on geology were published until after the War, in 1921.

Terra Nova Expedition, 1910 (Geology). Vol. 1, No. 1.

Seward had available Priestley's specimens of fossil wood from the Beacon Sandstone and Wilson's specimens from Buckley Island collected with great patience and endurance on the way back from the Pole. The fossil trees from the Priestley Glacier were described and named *Antarcticoxylon Priestleyi*,⁽²⁾ and

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(1) Limestones containing fossils belonging to several genera of Archaeocyathus have now been found *in situ* near the Nimrod Glacier in the Holyoake Range (approx. 82° S., 160° E.). The rocks are believed to form part of the Ross System. A distant view of Mount Hunt showed almost vertical limestone overlain by horizontal Beacon Sandstone.

Laird (M.) and Waterhouse (J. B.). Archaeocyathine Limestones of Antarctica. Nature. 1962, Vol. 194, pp. 860–1

(2) J. Walton re-examined the fossils and showed that the *Antarcticoxylon* can be referred to the genus *Rhexoxylon*, Bancroft, species of which were discovered in South Africa from beds of the Stormberg Series corresponding in age to the Trias in Europe.

Walton (J.). On *Rhexoxylon*. Bancroft — . . . Phil. Trans. Roy. Soc. London. 1923, ser. B., Vol. 212, pp. 79–109.

Seward also discovered in the specimens a winged spore which he named *Pityosporites antarcticus.* *Antarcticoxylon* he regarded as a distinct type of Gymnospermous plant not affording any very satisfactory evidence of geological horizon. The spore he considered afforded some evidence of the existence in Antarctica of an Abietineous conifer, possibly in lower Mesozoic, e.g. Rhaetic times. He added, however: 'on geographical grounds it would seem more probable that the spores belonged to some plant allied to *Podocarpus*, *Dacrydium*, or *Microcachrys*, genera [Coniferal] possessing winged pollen and at the present day characteristic of the southern hemisphere' (Vol. 1, p. 24).⁽¹⁾

Seward's conclusion as to the age of the part of the Beacon Sandstone in which the fossil stems and the spore were found is as follows: "So far as *Pityosporites* is concerned there is obviously no reason why the rock should not be of any age, from, say the latter part of the Trias upwards. There is, moreover, not sufficient reason for asserting that *Antarcticoxylon* could not have come from beds higher than the Jurassic" (p. 24). These discoveries were interesting enough in themselves but still greater interest attaches to Seward's studies of the plant remains collected from the moraines between Mount Darwin and Buckley Island on the Beardmore Glacier. Seward identified and described *Glossopteris indica*, a variety of this, var. *Wilsoni*, and other fragments of Glossopteris flora. This was the first indication of the existence of Glossopteris in Antarctica and it opened up problems of distribution and of climate of very great geological interest. As regards age Seward noted that

> " . . . the genus ranges from the Upper Carboniferous or Lower Permian rocks to the Rhaetic period. It is, however, not improbable that *Glossopteris* appeared on the Antarctic continent earlier than in other parts of the southern province . . . the probability is that the beds are Permo-Carboniferous in age: . . ."

Vol. 1, No. 2. On a moraine of the Mackay Glacier off Granite Harbour Debenham found dermal plates and scales of fish "in pieces of shale and shaly sandstone which are identical in outward appearance with the bands of shale that are found in the lower layers of the Beacon Sandstone, both in Granite Harbour . . . and in the Depot Nunatak on the Ferrar Glacier" (p. 110). They were described and figured by Smith-Woodward (vol. 1, no. 2) who named two new species of ostracoderm from plates and a ribbed spine, and also a new species of *Holoptychius* from several somewhat imperfect scales. Although these remains were so fragmentary that few of them could be definitely named he considered that they were sufficient to prove an Upper Devonian age for the shale fragments in which they were found (p. 60).

⁽¹⁾ This second suggestion of Seward's is the one favoured by S. Manum who has recently re-examined the type specimen, re-described it, and given a new definition of *Pityosporites.*

Manum (S.). On the genus Pityosporites Seward 1914 with a new description of *Pityosporites antarcticus* Seward. Nytt. Magasin Botanik, 1960, vol. 8, pp. 11–15.

The two palaeontological reports suggested an extensive time-range for the Beacon Sandstone Group, from Upper Devonian to Permo-Carboniferous, possibly Rhaetic.

Vol. 1, No. 4a. The lithology and distribution of the Beacon Sandstone was described by Debenham. He noted its immense extent and great thickness. In the Terra Nova region he noted the presence of coarse tuffs containing charred fragments of stems, and both here and at Granite Harbour sandstones with bituminous cement. Bands of coal were confirmed in the Granite Harbour region, as well as at Buckley Island on the Beardmore Glacier, while in the Granite Harbour district ripple-marks and sun-cracks gave evidence of 'a sandy waste with occasional pools of shallow water' (p. 107). On the Beardmore the moraine from Mount Darwin shows a preponderance of calcareous sandstone, and at Buckley Island a good proportion of the specimens collected by Wilson, are impure grey limestone. The limestone-breccia in which the *Archaeocyathus* was found by Shackleton's Expedition in the western moraine of the Beardmore is thought to come 'from the very base of the sediments as seen in Mount Bell'. This is in line with Edgeworth David's suggestion that the breccia is at the base of the Beacon Sandstone, the fragments being derived from strata in another locality not now exposed (p. 118).(1)

Vol. 1, No. 4b. The Northern Party of the Terra Nova Expedition under Commander V. L. A. Campbell was the first party to make a thorough examination of the green slaty rocks first discovered at Cape Adare by the Southern Cross Expedition (1898–9). Priestley assisted by the other members of the party collected from outcrops wherever they could be reached along the west coast of Robertson Bay. The rocks have been described by R. H. Rastall and Priestley (vol. 7, No. 4b). The Slate-Greywacke Formation, as it was named, consists of green-grey slates with some gritty and some small pebbly bands. Interesting variations are described. Some of the greywackes contain carbonates, usually siderite but sometimes calcite, and often aggregated into spots. Some of the finer grained rocks are chloritic and rather calcareous mudstones. At several localities pyrite cubes are frequent, and it was mainly specimens of this type that were collected by Borchgrevink and Louis Bernacchi on the Southern Cross Expedition. No fossils have been found in the Slate-Greywacke Formation of Robertson Bay. With regard to their age Rastall wrote: "The general appearance of the rocks with their prevailing grey and green colours, suggest a considerable age: in fact they present the characteristics usually associated with Palaeozoic or Algonkian sediments. Among British formations their nearest analogue is to be found in the Ingletonian series, to which indeed they show a strong resemblance" (p. 128).

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(1) See footnote (1) page 188.

The Metamorphic Rocks that form the Basement of the Antarctic Horst are exposed at many points *in situ* in the Kukri Hills and south of New Harbour in the McMurdo Sound Region, and boulders are found on Ross Island, along the coast in the direction of Granite Harbour, and many erratics of metamorphic rocks were found in the moraines of glaciers coming down towards Terra Nova Bay. They are described in vol. 1, No. 5.

Vol. 1, No. 5a. In the McMurdo Sound Region they comprise a considerable thickness of schists, with some crystalline limestones. Probably associated with these are green para-pyroxene-granulites that are found only as erratics or as inclusions in intrusive granites. The crystalline schists include garnet-sillimanite-gneiss, cordierite-bearing garnet-gneiss, and biotite-schist with abundant pseudomorphs after andalusite. These, with the pyroxene-granulites and limestones, represent highly metamorphosed argillaceous, calcarcous and dolomitic sediments probably of Precambrian age. Fairly closely associated with some of these rocks is a biotite-hornblende-gneiss and some amphibolites and hornblende-schists. The gneiss may have been intrusive into the crystalline schists but contacts were not seen.

Edgeworth David and Priestley regarded these metamorphic rocks as Precambrian and the report on the Terra Nova collections endorses this view. Attention was drawn to very similar associations in the Precambrian of Burma, Ceylon, Madagascar, and East Africa, and in South Australia. Very close comparisons can be made with the Precambrian rocks of the Hutchison Series in Southern Eyre Peninsula described by C. E. Tilley in 1920 (p. 144).

Vol. 1, No. 5b. Metamorphic rocks were found *in situ* at five localities in the Terra Nova Bay region between the Priestley and the Campbell Glaciers. These are garnetiferous biotite-gneiss, a sillimanite-bearing muscovite-biotite-schist, and several pieces of a pyroxene-pegmatite similar to some 'intrusions' in the crystalline limestones enclosed by grey granite in the Granite Harbour region. At one place, Cape Sastrugi, the rocks were quartz-schists, more or less micaceous, and some of them of more gneissic texture. A tourmaline-bearing pegmatite was prominent at this locality. A few miles to the north of Cape Sastrugi the rocks *in situ* are fine-grained well-foliated gneiss grading into biotite-schist and succeeded to the north by a porphyritic biotite-orthoclase-gneiss.

Four glaciers were discovered coming down from the mountains to the north of the ice sheet at Terra Nova Bay: the Campbell Glacier from the direction of Mount Melbourne with a tributary, the Boomerang, coming in on its western side; and, further to the west the Priestley Glacier with a tributary, the Corner Glacier, joining it on its eastern side (fig. 7, p. 146).

The erratics collected from the moraines of these glaciers yielded a great assortment of rocks among which metamorphic rocks and fragments of Beacon

Sandstone were the most abundant. Priestley collected 770 specimens (exclusive of the erratics of sedimentary formations). The metamorphic rocks among the erratics are classified as biotite-gneiss, garnetiferous biotite-gneisses with sillimanite and/or cordierite, muscovite-biotite-schists, again sillimanite-bearing, various quartz-granulites of sedimentary origin, and numerous examples of the pyroxene-granulites already mentioned from the McMurdo Sound Region. Except for a chondrodite-limestone, crystalline limestones are almost unrepresented but it will be realized readily that granular rocks as friable as weathered crystalline limestones are hardly likely to survive as erratics under Antarctic conditions.

This assemblage is similar to the metamorphic rocks of the McMurdo Sound Region, and one can probably assume tentatively that they represent the same formation, but there are in addition erratics of fine-grained *graphitic mica-schists* believed to represent slates or shales altered by thermal metamorphism. Some contain ovoid aggregates of biotite, one carries well-developed chiastolite, and another, a "spotted schist", has spots consisting in part of muscovite probably pseudomorphing andalusite or cordierite. In one specimen pale yellow garnets have formed in 'eyes' of quartz and biotite round nuclei of pyrrhotite. The garnets are similar to some described in contact metamorphosed rocks from Bastogne in the Belgian Ardennes (p. 162).

By listing and tabulating all the specimens collected from these moraines an attempt was made to get some idea of the regions occupied by the different groups of metamorphic rocks (p. 163). What emerged was that the biotite-gneiss and the garnet and cordierite-biotite-gneisses were well represented in the Campbell and Boomerang moraines and in the moraines of the Corner Glacier but were scarce in the western (or outer) moraine of the Priestley. The quartz-granulites and the few specimens of crystalline limestones occurred in the eastern moraine of the Corner Glacier, while the outer, western moraine of the Priestley Glacier contained few biotite-gneisses, more quartz-granulites, all the para-pyroxene-granulites, and all the graphitic mica-schists. It was this western moraine of the Priestley Glacier that yielded also abundant erratics of Beacon Sandstone, and the specimens of fossil wood.

Vol. 1, No. 6. The Plutonic and Hypabyssal rocks were described in 1924. In the region extending from the Ferrar Glacier and the Kukri Hills to Granite Harbour two distinct granites have been recognized, an older, grey, hornblende-free granodiorite with associated aplitic dikes, and a younger pink hornblendic biotite-granite. The same two granites had been recognized by Ferrar and they had been distinguished by Mawson on Shackleton's Expedition, as the grey granite of Mount Larsen type, and the pink granite of Cape Irizar. Much additional information on these granites was obtained by Debenham and recorded on his own plane-table maps. It seems possible that the grey granite (Granite Harbour type) may form part of a great intrusive mass of which the edge is exposed along or near the coast. Observations of the exposed upper surface at the outcrops in the Ferrar Glacier region, and perhaps also in Granite Harbour, indicate a remarkably level surface. In the Ferrar Glacier region the grey granite is often separated from the overlying Beacon Sandstone by a quartz-dolerite sill. The granite contains very numerous xenoliths of gneisses, pyroxene-granulites and limestones. These are supposed to represent fragments of the foundered roof of the granite intrusion. At the Flatiron in Granite Harbour Debenham's mapping showed a very interesting and close relation between the distribution of para-pyroxene-granulite xenoliths and the development of a hornblendic facies of the granite with large hornblende insets and occasional growth of orbicular structures in the granite.

Marble Dike and Marble Outcrop are large masses of white crystalline limestones enclosed by the grey granite, and interesting metamorphic effects were observed at contacts where these are intruded by aplite dikes. One result is the formation of veins containing large green diopside crystals with orthoclase, quartz, and abundant sphene. Rocks similar to these diopside-orthoclase rocks were found by A. F. Zealley associated with masses of limestone in Donegal, and another possibly similar occurrence has been described by A. Lacroix from St. Brévin (Brittany). At other places acid dikes cutting the inclusions of crystalline limestone and pyroxene-granulite have produced a garnet-actinolite-idocrase-calcite assemblage with wollastonite at the actual junction (p. 182).

The younger of the two granites in the McMurdo Sound Region is a pink hornblendic biotite-granite. This is recorded from Granite Harbour, Cape Gregory, Cape Irizar (described by Mawson), and from Prior Island (near the Davis Glacier).

A similar granite occurs in the Kukri Hills. Ferrar believed it was younger than the dolerite sills that cut the Beacon Sandstone but the geologists of Shackleton's expedition of 1907–9 took the opposite view, and Debenham's observations [and a re-examination of some of the specimens on which Ferrar's opinion partly depended] confirms it is older than the Quartz-dolerite (p. 185). At a section which Ferrar interpreted as showing granite penetrating dolerite Debenham found that triangular masses of granite were hoisted up and enclosed within the quartz-dolerite sill (fig. 5, p. 184).

An interesting series of dikes: quartz-orthoclase-porphyries, orthoclase-porphyries, and lamprophyres (sometimes as composite dikes) is associated with this younger granite. In the Terra Nova Bay region investigated by the Northern Party erratics from Evans Beach include various specimens comparable with the grey biotite-granite from Mount Larsen and also dikes of aplite, pegmatite and the lamprophyres, vogesite and spessartite. Two boulders of enstatite-peridotite were the only representatives of ultra-basic rocks collected on this Expedition.

Rocks *in situ* near Evans Coves, in the Northern Foothills, Vegetation Island and the northern part of Inexpressible Island, comprise a biotite-granite and a diorite (Northern Foothills type). The diorite is intricately penetrated by microgranite as well as by aplite and pegmatite veinlets. These rocks were described (in 1924) on the assumption that the diorite and the microgranite were separate intrusions. It was noted that the diorite has features recalling those of some so-called 'basic patches' occurring in certain granites, such as that of Newry, County Down. They were also compared to segregations of dioritic rocks in some granites of northern New South Wales (p. 209). In the light of recent work on similar assemblages of dioritic and granitic rocks elsewhere, such as for instance that described by A. K. Wells and S. W. Wooldridge in 1931 at Ronez and Sorel Point in Jersey, it is probable that the diorites of the Northern Foothills would re-pay re-examination.

Erratics high upon Cape Adare include rocks resembling some of those from the Terra Nova Bay region, and others resembling some of the granites and dike rocks from Granite Harbour (p. 214).

The source of these erratics is unlikely to be so far south as Terra Nova Bay or Granite Harbour. Between Mount Melbourne and Robertson Bay (and Cape Adare) is 200 miles of still unknown country and it is Priestley's opinion that somewhere in this area, possibly in the Admiralty Range, e.g. in the region of Mount Sabine, are outcrops of granitic rocks similar to those we know in Terra Nova Bay, Granite Harbour and the Ferrar Glacier region.

There are a few plutonic types among the erratics in the Murray Glacier moraines. These are dioritic rocks ranging from granodiorite to olivine-bearing types. Some of them are similar to the dioritic rocks of Terra Nova Bay but they are not identical (pp. 217–8).

The Beardmore Glacier yielded only fragments of granite in the moraine near The Cloudmaker. These may be similar to the grey granite (Granite Harbour type). No outcrop was seen so it is possible that the two small fragments collected are from a pebbly band in the sedimentary formation (p. 226).

The extensive sills intruding the Beacon Sandstone in the McMurdo Sound region found, first by H. T. Ferrar, are quartz-dolerites. They are now to be known as the Ferrar Dolerites.(1) They have been found by the geologists of the Terra Nova Expedition also in the Granite Harbour region, in the western moraine of the Priestley Glacier, and on the Beardmore Glacier. These rocks have been described by G. T. Prior and by W. N. Benson in the reports of the earlier expeditions. Both authors have drawn attention to the close similarity between them and widespread intrusions of late Mesozoic and probably Cretaceous age in Natal, Brazil, British Guiana, and particularly in Tasmania. The resemblance with the Tasmanian dolerites is so close that Benson suggested a similar, Cretaceous, age for the dolerites of South Victoria Land (p. 198). All the specimens of quartz-dolerites collected by the Polar party were carefully examined and it was established that nearly all of them are typical of the quartz-dolerites of the McMurdo Sound region. A few of them are exceedingly fine-grained varieties and one shows small round vesicles filled with zeolites (p. 222). Similar fine-grained rocks with many large zeolite-filled vesicles were associated with typical quartz-dolerites and with Beacon Sandstone, in the western moraine of the Priestley Glacier. These have been shown to be tholeiites (vol. 2, no. 3, p. 172) and it is possible, judging from their vesicular habit, that they are effusive equivalents of the intrusive quartz-dolerites. The only other indication of vulcanicity associated with the Beacon Sandstone formation in South Victoria Land is the record of 'dark-brown grits with much volcanic debris as well as the almost universal fragments of stems' from morainic material in the Terra Nova Bay region (p. 111).

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(1) Harrington (H. J.). Nature, 1958, vol. 182, p. 290.

Vol. 2, No. 1.

Thirty years elapsed between the publication of the report on the plutonic and hypabyssal rocks and that on the Volcanic rocks of the Ross Archipelago, which are reported on in No. 1 of this volume (pp. 1–107).

The notes on the distribution of the volcanic rocks were compiled chiefly from "The Physiography of the Ross Archipelago" by Frank Debenham (1923) and from field-catalogues and labels. A brief summary listing the main groups of the volcanic rocks encountered concludes this introductory part of the chapter and the detailed petrography and chemistry of each group follows (p. 19).

At Mount Erebus the kenytes are the most recent lavas; phonolitic trachytes and porphyritic basalts are among the earlier ones. Considerable interest attaches to the 'anorthoclase' phenocrysts of the kenytes, which are found not only in the lavas but loose on the sides of the crater. They were analysed by E. D. Mountain in 1925, and classified by him as potash-oligoclase.

At 'Mount Cis', a parasitic cone on Erebus, there are many inclusions some of which are identifiable as having been sandstone. This fact, first recorded by Edgeworth David and Priestley (1914), is evidence that the Beacon Sandstone, faulted down to a considerable depth, lies beneath the volcanic pile on Ross Island (p. 26).

In the chapter on the basalts four different areas are treated separately, viz.: Mount Erebus and the Dellbridge Islands (p. 68): Hut Point Peninsula (p. 76); Cape Barne (p. 86); and the Mainland opposite Ross Island. The likelihood of recent basalts being found on the mainland was realized by G. T. Prior as Ferrar's collection contained a specimen of basalt found on the Ferrar Glacier.

The geologists of the Terra Nova Expedition located two distinct areas of small scale, recent volcanic activity, one in the Koettlitz Glacier Valley, and the other in the Taylor Valley (p. 18). At this latter locality the basalts contain inclusions of Beacon Sandstone and of quartz-dolerite. In composition these 'mainland' basalts resemble those of Hut Point Peninsula, where the basalts appear to be the most recent of the lavas. Priestley⁽¹⁾ has drawn attention to the records of erratics of kenytes lavas on the mainland in the neighbourhood of the Koettlitz Glacier and in the Taylor Valley, and, revising his earlier opinion in the light of additional evidence, he considers there is a pretty good indication that separate centres of eruption, supplying kenyte lavas, occur in the neighbourhood of Mount Discovery, a 9,090 ft. conical mountain between the Koettlitz Glacier and Minna Bluff. He also considers that the kenyte erratics recorded both by himself and Edgeworth David⁽²⁾ and by Griffith Taylor⁽³⁾ in the Taylor Valley may have their origin in the upper reaches of the "South-West Arm" of the Ferrar Glacier.

Vol. 2, No. 2. The volcanic rocks from Cape Adare were collected by Priestley with the Northern Party which landed there on 18th February 1911. He collected rocks *in situ* from the cliffs, erratics from a high plateau on the top of the Cape, pebbles from the beach, and erratics from the Newnes and Murray Glaciers. With the exception of a phonolite and trachytoid phonolite all the lavas are basalts. Their chemical composition is discussed in this, the final, number (No. 3) of these reports. One of the basalts *in situ* at Cape Adare contains large numbers of partly digested xenoliths of sedimentary rocks. It is thought that these are derived from the slate-greywacke formation which outcrops in Robertson Bay (p. 122). Particular interest attaches to a boulder-bearing agglomerate on the cliff face. Priestley found in it erratics of green 'quartzite' and what appeared to be dolerite as well as boulders of igneous rocks. Some of the latter prove to be sanidinite, others are alkali-trachytes related to some of the rocks found as erratics on the plateau on the top of Cape Adare (p. 135) and as pebbles on Ridley Beach, and well-crystallized sodalite-trachytes. The matrix of the agglomerate is volcanic tuff. The agglomerate is probably the product of a volcanic vent which in some way

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(1) Priestley (R. E.). Physiography (Robertson Bay and Terra Nova Bay Regions). Brit. (Terra Nova) Ant. Exp., 1910–1913. 1923, p. 55.

(2) David (T. W. E.) and Priestley (R. E.). Brit. Ant. Exp.. 1907–9. Geology, vol. 1. 1914. p. 95.

A footnote on this page records that "The Western Party of the Scott Expedition 1910–13 have since examined this district in detail, and Debenham found kenyte and basalt *in situ* in the upper reaches of the glacier". The only specimens in the collection from this site are basalts; they are described on pp. 88–90 of this volume. A view of the recent craters on the mainland in 'Dry Valley' is shown in Debenham's report on the recent and local deposits (Vol. 1, No. 3. p. 71).

(3) Taylor (Griffith). The physiography of the McMurdo Sound and Granite Harbour Region. Brit. Ant. (Terra Nova) Exp. 1910–1913, 1922, p. 100.

has involved blocks of quartzite and dolerite erratics brought within its reach by very early glaciation.

In the report on Recent and Local deposits (Vol. 1, no. 3, 1921) Debenham in describing the small craters on the mainland remarked that one at least was active after the maximum extension of the ice (p. 89) and in the crater of Crater Hill in the Hut Point Peninsula he recorded small erratics of granites, granulites, porphyries and sandstones but these are all small and have been carried into the Crater by wind not by ice (p. 82).

From Cape Adare the Northern Party moved by ship to Evans Coves in Terra Nova Bay. In this region a few erratics of volcanic rocks were found in the moraines of the Boomerang and Campbell Glaciers. These are basalts and alkali-trachytes allied to those of Cape Adare. It seems likely that they come from the neighbourhood of Mount Melbourne (p. 174), of which no authentic specimens had ever been obtained.

Priestley (1923, p. 49) has suggested that the main flow of the Priestley Glacier "is also derived . . . from some local ice-sheet, banked up in rear of Mount Melbourne", but, apart from the tholeiites, the only erratics of volcanic rocks from the Priestley Glacier are a mugearite and a fine-grained olivine-free basalt that may be related to the tholeiites rather than to the younger volcanic rocks.

The only other possibly volcanic rocks from the Terra Nova Region are the tholeiites with zeolite-filled vesicles from the Priestley Glacier mentioned above (p. 173).

Two boulders of kenyte were found on the beach at Evans Coves. They are thought to have been transported on ice-floes from Ross Island and their present position affords evidence of recent elevation of the beach. In Granite Harbour four erratics of other volcanic rocks were collected by Debenham. They are of porphyritic ankaramitic basalt and limburgite, unlike any of the volcanic rocks described from Ross Island.

The last chapter (V) describes the pebbles dredged in the Bay of Whales at depths of 355–457 metres on 4th February, 1911. These represent morainic material probably derived from King Edward Land and parts of Marie Byrd Land. Quartzites, schists, gneisses, a few sandstones, and vein-quartz are all represented. Quartz-feldspar-porphyries and rhyolite, or rhyolitic tuff, are frequent but otherwise volcanic rocks are very rare, less than one per cent of the haul.

In conclusion the author of this volume wishes to record his thanks to the many members, past and present, of the Department of Mineralogy of the British Museum (Natural History) who in various ways have helped him with the work, and to Dr. G. F. Claringbull, Keeper of Minerals, who has given the author facilities to continue working in the Department. In particular he wishes to record his great indebtedness to Sir Raymond Priestley and Professor Frank Debenham, geologists on the Terra Nova Expedition. At intervals during many years, as successive stages of the work of describing their collections were reached, they came again and again to his help. Much of the geology of South Victoria Land is now known, and this is owed to the men who initiated and directed the extensive scientific programme of the Expedition, Captain Robert Falcon Scott and Dr. Edward A. Wilson, and to the geologists who with great patience and endurance collected, carried and man-hauled on sledges a great collection of geological material and, in the comparative comfort of the base huts, catalogued and labelled it all.

Duplicate specimens from this collection have been given to the Geological or Mineralogical Departments of many Universities and in the Department of Mineralogy of the British Museum there are over 1,500 registered specimens. These have now all been described.

EXPLANATION OF PLATE

PLATE I

THOLEIITE ERRATICS FROM THE OUTER MORAINE OF THE PRIESTLEY GLACIER

Fig. 1. A medium-grained 'basalt' related to the quartz-dolerites. Laths of labradorite are partially enclosed by plates of pyroxene. Dark 'glass' fills the interstices. The large vesicle is occupied by a single crystal of stilbite. B.M. 1953, 89 (20a)=1710. × 14·5, p. 167.

Fig. 2. Micro-insets of pyroxene occur occasionally in a fine-grained groundmass of laths of labradorite, granular pyroxene and a light mesostasis, perhaps a cryptocrystalline quartz-feldspar aggregate. B.M. 1953, 89 (15)=1836. × 36, p. 169.

Fig. 3. Laths of labradorite form a mesh within which lie platy crystals and grains of pyroxene and dark mesostasis. The vesicles are filled by zeolites. B.M. 1953, 89 (1)=1254. × 36, p. 170.

Fig. 4. Spherical vesicle filled by black glass in which have crystallized slender laths of feldspar and prisms of augite. Small vesicles, within the larger one, are filled with chlorite (bottom right). The rock consists of plagioclase laths which penetrate and are partly enclosed by augite. Interstices are filled by dark glass. B.M. 1953, 89 (17)=1783. × 36, p. 170.

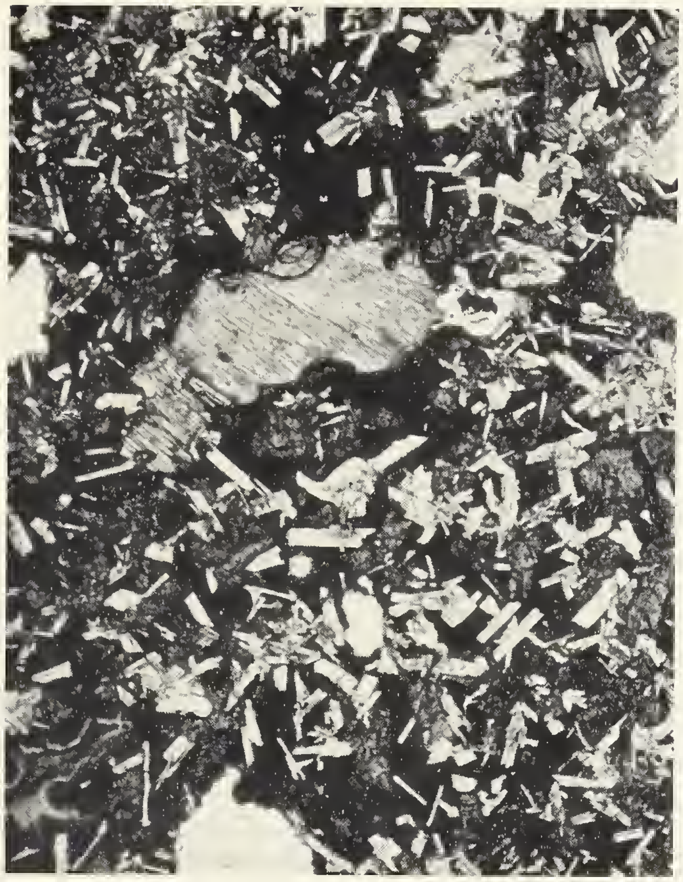

Fig. 1.

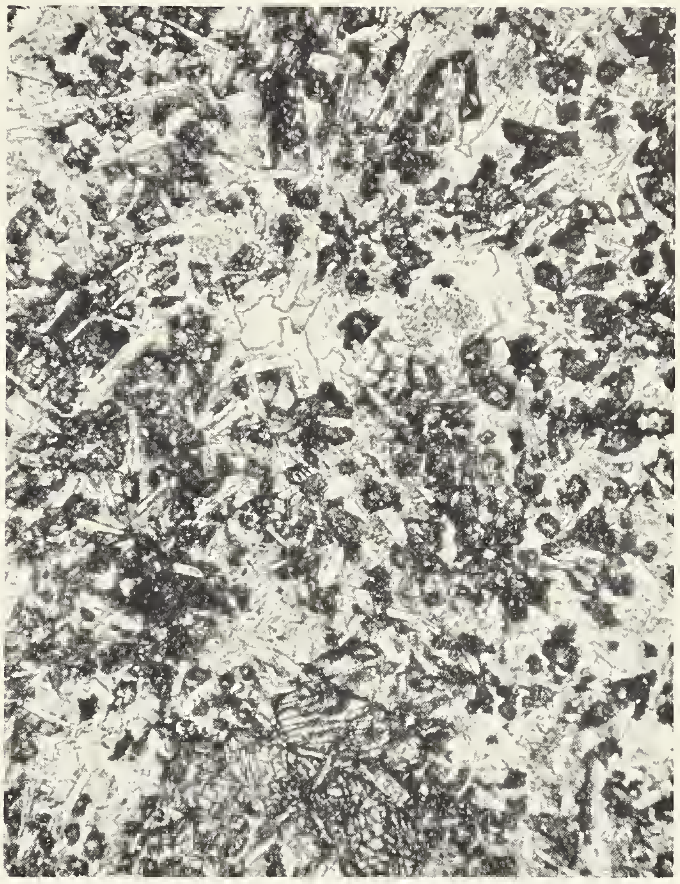

Fig. 2.

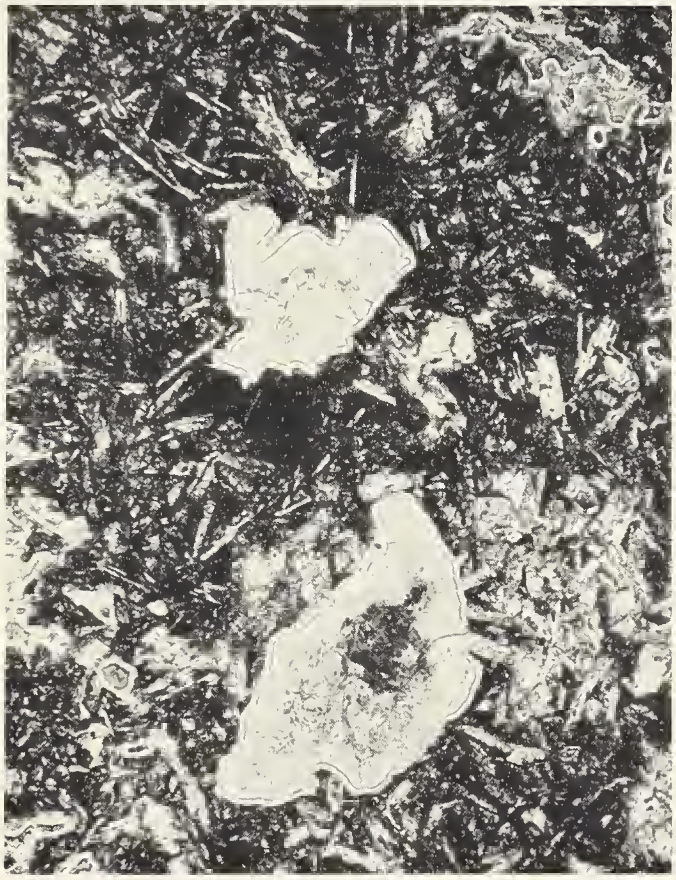

Fig. 3.

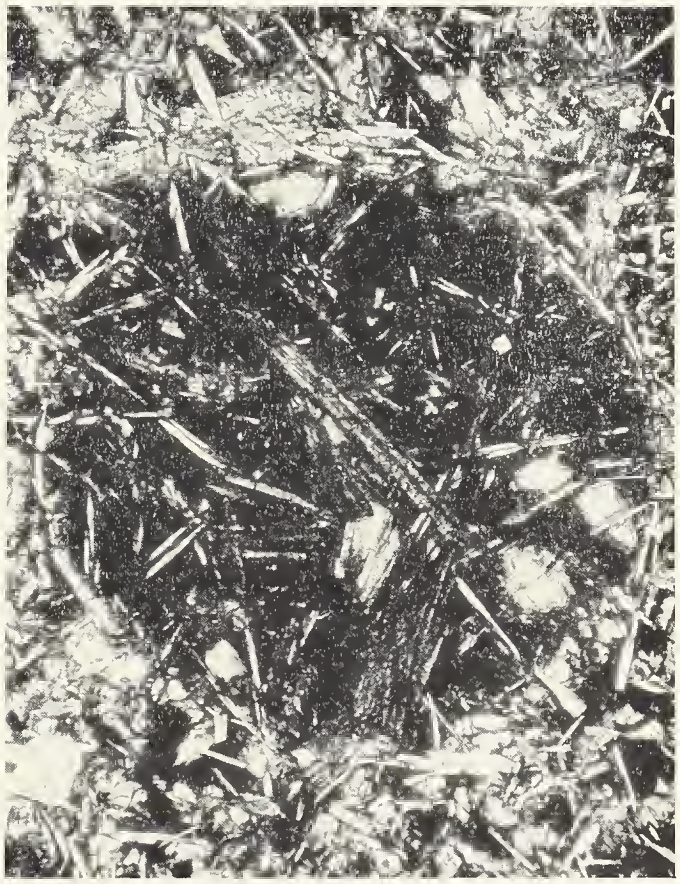

Fig. 4.

D. L. Williams, B.M. (Nat. Hist.), photo.

THOLEIITES FROM THE PRIESTLEY GLACIER

BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910
NATURAL HISTORY REPORTS

Geology. Vols. I and II

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